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This item has been reviewed by both the Navy and DOE. Both have no objection to its declassification and release. I also had Dr. McAninch (J9NTE) review it. We believe it can be declassified based on the deletions.
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DISTRIBUTION OF THE RADIOACTIVE DEBRIS AND ASSOCIATED NUCLEAR RADIATION FROM UNDERWATER NUCLEAR EXPLOSIONS (U)

by

E. A. Schuert

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U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

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ADMINISTRATIVE INFORMATION

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Eugene P. Cooper

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Scientific Director

D. C. Campbell

D.C. Campbell, CAPT USN
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CLASSIFICATION GUIDANCE

Information in this report is classified as follows:

1. General Underwater Explosion phenomenology is classified Confidential.

2. Conclusions regarding the overall state of the art capability are classified Secret.

3. DELETED DOE

4. KT yields for Wahoo and Umbrella are classified Confidential-Formerly Restricted Data, Group 1.

5. Yields of stockpile weapons are classified Secret-Formerly Restricted Data, Group 1.

6. Association of yield and any device name, Mark, TX or Mod number with a particlular shot is classified Secret-Restricted Data, Group 1.

7. Yield of Shot Swordfish is Secret-Formerly Restricted Data, Group 1.

8. Depth of burst for Swordfish is classified Confidential, Group 4.

9. Device design information is classified Secret-Restricted Data, Group 1.

ABSTRACT

A technical review of the literature on the distribution of the radioactive debris and the associated nuclear radiation from underwater nuclear explosions is presented. This review, or material based on it, is to be included as Chapter 11 in the planned DASA book Underwater Nuclear Explosions, Part 1 - Phenomena.

The history of the fission products is followed from the time of detonation. The free-field gamma radiation phenomena are discussed for surface, very shallow, shallow, deep, very deep, and extremely deep scaled depth ranges by evaluation of three major sources: the early above-surface phenomena, the base surge, and the residual radioactivity in the ocean.

The state of the art is summarized, and the direction of current research and suggested future research are discussed.

It is concluded that no adequate comprehensive radiological prediction system exists in the literature for underwater nuclear explosions.

SUMMARY

The Problem

To condense, into one chapter, the basic concepts involved in the distribution of the radioactive debris and the associated nuclear radiation from an underwater nuclear explosion. This chapter, or material based on it, is to be part of the planned DASA book on Underwater Nuclear Explosions, Part I - Phenomena.

Findings

The state of the art is such that a fairly well-defined conceptual description of the radiological effects from underwater nuclear explosions has been made. In certain specific areas adequate prediction systems are available; however a comprehensive prediction system is far from being achieved.

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FIGURES (Contd)

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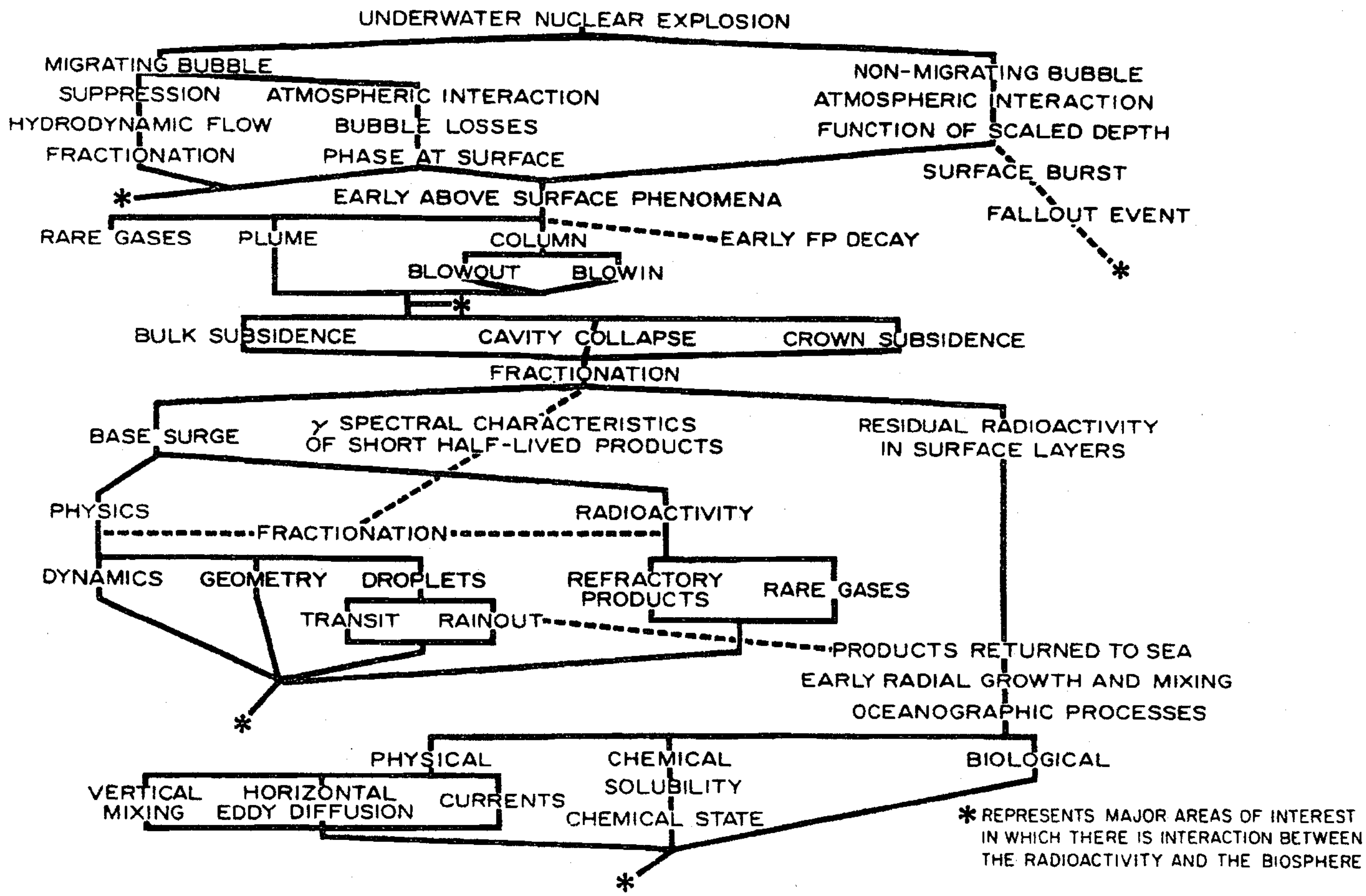
FOREWORD

This report was prepared as a basis for the preparation of Chapter 11 of the planned DASA book on Underwater Nuclear Explosions, Part 1 - Phenomena. The completed volume will consist of the following:



Frontispiece. Major Phenomena Influencing the Distribution of Debris From an Underwater Nuclear Explosion.

UNDERWATER NUCLEAR EXPLOSIONS.

PART I - PHENOMENA*

CHAPTER 11

DISTRIBUTION OF THE RADIOACTIVE DEBRIS AND ASSOCIATED NUCLEAR RADIATION

11.1 INTRODUCTION

The design of nuclear warheads for naval use underwater had as its primary objective the capability of doing extensive damage by shock effects. In this regard the nuclear explosive with its extremely high energy density was a successful addition to the Navy arsenal; however this development brought with it the problem of radioactivity.** This new variable added complexities to the employment of naval weaponry to the extent that a great deal of research was carried out on the radiological effects from underwater nuclear explosions, the subject matter of this chapter.

The import of these effects was relatively slow in being accepted, as was that of fallout from land surface nuclear explosions. The distribution of the radioactive debris and their associated nuclear radiations certainly were anticipated prior to Operation Crossroads. However the magnitude of the problem was not fully realized until after Operation Hardtack in 1958 where it was demonstrated that the above-surface phenomena produced by an underwater nuclear explosion carried such quantities of radioactive debris that the free-field gamma radiation doses to personnel could seriously hamper naval operations.

Although research had been done on underwater shock effects and bubble hydrodynamics prior to the nuclear era, the relationship between these effects and the above-surface phenomena was studied little.

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* See Foreword.

**The release of nuclear radiation associated with an underwater explosion has been reviewed in detail by Schuert and Werner (1964).

Consequently, with the development of the nuclear weapon it was required to relate the above-surface phenomena to the underwater hydrodynamics and to study the entire event as a dispersion mechanism for the fission products.

It is important to realize that the radiological effects of an underwater explosion are drastically different from those of a land surface and an air burst. Air bursts, wherein the fireball does not intersect the surface of the earth, disperse their fission product debris high in the atmosphere. The dispersal of the radioactive fallout is world wide, and it returns to the earth's surface over long periods of time, highly diluted and degraded. The land-surface burst is the classical local fallout event. Great quantities of earth are drawn into the fireball, mixing with the fission products and carried aloft. Most of the fallout returns to the surface locally, creating a highly radioactive surface-environment which slowly decays over a period of weeks. Some residual radioactivity in smaller sized particles remains aloft for long periods and contributes to the intermediate and the global fallout.

The underwater explosion ejects radioactivity into the lower atmosphere accompanied by large quantities of water. This mixture rapidly falls back to the surface in the immediate vicinity of surface zero. This rapid subsidence of water develops a base surge aerosol which propagates outward radially along the surface of the water. The base surge is a major carrier of fission-product debris in the atmosphere. The fraction of the debris that remains airborne is less than that which immediately returns to the sea.

The entire phenomenon will be discussed in detail in this chapter. However it should be pointed out at this time that underwater explosions should not be considered fallout events as described above; rather their important atmospheric transport mechanism is transient, much like a wind-carried fog.

The development of an extremely hazardous atmospheric and oceanic radiological environment subsequent to the underwater detonation of a nuclear weapon made it apparent that this new variable, radioactivity, had to be considered and balanced with the more familiar effects, underwater shock and air blast. Both offensive and defensive tactical doctrine had to be re-evaluated in the light of this new variable. For instance, the determination of new ship safe-standoff distances and aircraft weapon-delivery criteria, and indeed the design of the weapon and its fuzing system, require knowledge of the space-time distribution of the radiation fields resutling from the explosion of such a warhead.

The description of the radiological phenomena in this chapter has relied primarily on data from a limited number (five) of underwater

nuclear weapons tests conducted to date. The information is further limited by the fact that two of the tests contributed very little surface radiological data, and none contributed directly to an understanding of the very early atmospheric radiation fields of especial interest in the aircraft-delivery problem. Consequently, past experience in the field of underwater chemical detonations, and theoretical studies and continuing high-explosive tests, have been exploited to fill the gaps.

This chapter is limited to describing the gamma radiological effects from underwater nuclear explosions as free-field phenomena. The interaction of the radioactive material and its associated nuclear radiations with vehicles, structures, and personnel is the subject of Part II of this book.

11.2 DISTRIBUTION OF THE RADIOACTIVE DEBRIS

The radiological effects from underwater nuclear explosions are seen to be very complex phenomena when one considers the wide range of yields and detonation depths of interest and how changes in these variables drastically affect the history of the fission products and induced activities. The distribution of this radioactivity depends upon the hydrodynamics of the explosion and the resultant water-bubble motion. This relationship may affect not only fission-product transport but also may have a direct bearing on fission product fractionation.

The most important factor in the development of the gamma radiation fields, and consequently of exposure rates and exposure, is the extremely early time after fission, at which radioactive products are available to interact with the environment. The initial radiation associated with the rising columns and plumes in the atmosphere can be available for interaction with aircraft as early as several seconds post-detonation, and surface ships can be engulfed by a highly radioactive base surge aerosol within 30 seconds. These interactions occurring at such very early times imply very high exposure rates and very rapid decay. Consequently, any transport mechanism must be well-delineated because of the time scale over which it is operating.

In this section examination will be made of the explosion, the bubble, the bubble oscillation and migration, the bubble sea-air interface interactions, the early above-surface phenomena, the base surge, and the residual radioactivity in the ocean, from the point of view of how the fission products are affected and how they are transported.

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Reference should be made to Chapter 2 (Snay 1966) for a more detailed discussion of the hydrodynamic phenomena involved.

11.2.1 THE EXPLOSION

The type of nuclear device employed has an influence on the quantity and type of radioactivity produced, as discussed generally by Schuert and Werner (Chapter 10). The fission product production in relation to the total yield depends upon the fissile material used and the type of reaction taking place. In addition to fission products, neutron-induced activities contribute to the total gamma radioactivity, and the part they play depends upon both weapon design and the immediate explosion environment. Since a detailed discussion of all possibilities of total gamma production is beyond the scope of this chapter, elaboration will be limited to examples representing a pure fission weapon and a thermonuclear device, with a hypothetical maximum neutron flux escaping to the underwater environment.

An instant after the detonation takes place essentially all of the radioactivity is produced, the contribution from neutron-capture products being some fraction of the total. DOE

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His results on the contribution to the total activity from the major induced products of Na^{24} and Cl^{38} are shown in Fig. 11.2:1, after being adjusted to a yield of 10 KT. DOE

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For explosions on the bottom, consideration must be given to possible contributions from induced activities other than Na^{24} and Cl^{38} as found in seawater. If it be assumed that bottom detonations will be in shelf waters, where terrigenous clays and $CaCO_3$ make up the bulk of the sediments, a cursory examination of their constituents suggests minor capture-product contribution to the total activity produced, for the major elements available, Ca, Si, Al, and Fe, produce insignificant quantities of induced radioactivity. Although this problem has not been investigated in sufficient detail over a variety of geological situations, any induced contribution from a bottom explosion can be assumed to amount to that calculated for infinite seawater.

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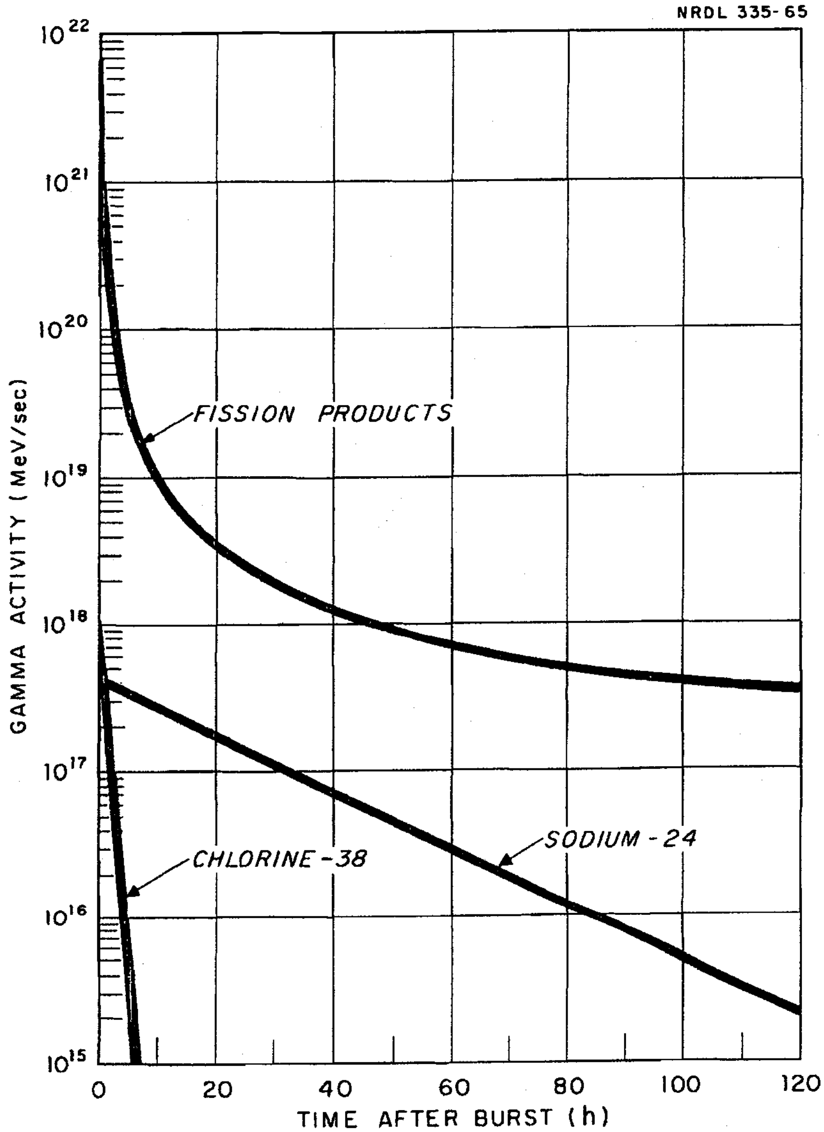

Fig. 11.2:1 Fission Product and Major Induced Gamma Radioactivity From a 10-KT, 100-Percent-Fission Underwater Explosion.

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Bursts on the surface are a special case. The upper half of the weapon, being unshielded by seawater, will produce a prompt neutron flux in the atmosphere. This neutron flux generates gamma rays consisting of those resulting from inelastic scattering of the neutrons and of nitrogen-capture gamma rays (see sections 11.2.4 and 11.3.2). In calculating the total induced products formed, Ferguson* estimates for a surface burst that one-third of the neutrons escaping from the device interact with the seawater and two-thirds with the atmosphere.

Table 11.2.1 presents estimates of the total gamma activity as a function of device design, environment, and time for a total yield of 10 KT. It can be seen that the contribution by induced radioactivity, from neutron interaction with seawater, to the total is never greater than 10 percent at the early times of military interest considered. However at times earlier than 0.5 hours the contributions by induced radioactivity will become more important to an unknown degree.

The limited examples discussed above suggest that the contribution from induced radioactivity to the total produced is minor. However further studies should be made for any specific set of total environmental circumstances.

The remainder of this chapter will be limited, in discussions of the quantity of radioactivity produced and its distribution, to pure fission weapons. The neutron-induced radioactivity contribution from the seawater environment will be ignored.

11.2.2 THE BUBBLE

Shortly after detonation, the fission products and most of the neutron-capture products are thought to exist in a sphere of energy several feet in radius about the point of explosion. The isotropic propagation of energy, initially as a radiative front, and shortly thereafter as an intense shock wave, initiates the development of the bubble. The initial bubble volume is defined at that time when the energy front has so degraded that it no longer can release enough energy to the water to cause further vaporization to take place. At this time and at the associated radial distance from the point of explosion, about half the initial energy is contained in the bubble and the remainder has been carried away as a shock wave. The internal thermodynamics of the nuclear bubble at this time are not well understood. The best theoretical estimates to date suggest the major constituent, water, to be in many physical states, from complete dissociation near the bubble center to water at the boiling point at the outer periphery. Further discussion of the thermodynamics of the initial bubble can be found in Snay (1956) and Kot (1964).

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*Private communication.

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The bubble, existing as a high-pressure, high-temperature sphere, then expands against ambient hydrostatic pressure to a maximum radius of hundreds of feet depending on the yield and depth of burst.

In order to estimate fission product distribution within a nuclear bubble as hypothesized by Snay (1960), Buntzen (1964) simulated the event at a very small scale with an underwater exploding-wire energy source. By means of a gold wire and a high-speed sampling device, he determined the distribution of the gold within the bubble at its first maximum by analyzing bubble-volume samples for gold as a function of radial distance, through neutron-activation analysis techniques. This ingenious experiment showed the wire-product distribution to fall off in concentration with an approximately inverse cube relationship with distance from the bubble center. Also Buntzen suggests that if the primary very-early, internal-bubble, transport mechanism is diffusion, then for the nuclear case one would not expect fractionation of the fission products within the bubble as a function of radius. This general distribution found experimentally at a very small scale is supported by the results of traced high-explosive studies of Kaulum (1965), and is in agreement with the theoretical work of Snay (1960).

Further theoretical work and measurement of the nuclear bubble constituents would be necessary before the location of the radioactivity in the nuclear bubble can be quantitatively described. Qualitatively, the radioactivity can be considered to be distributed within the bubble as a function of radius, with most of the products remaining within the central 1 percent of the bubble volume at the time of the first bubble maximum (see Snay, 1960). Further, the bubble atmosphere can be considered to consist of water molecules and salts, with an unknown fraction of non-condensable gaseous products from the high-explosive component of the warhead, dissociated water, and dissolved gases removed from solution in the seawater by the energy release on detonation. The fate of the contained radioactivity is a function of the bubble history and the scaled depth of burst, as discussed in the following sections.

11.2.3 THE UNDERWATER HISTORY OF BUBBLE AND ITS ASSOCIATED RADIOACTIVITY

A great deal of research has been done on the hydrodynamics of the underwater phase of the bubble motion; see Cole (1948), Keil (1956), and Kennard (1943) as examples. This complex motion, which plays a determining role in the ultimate distribution of the radioactivity, is strongly dependent upon the yield and depth of burst under consideration. In order to classify underwater explosions, depth categories have been established by Swift and Young (1962). Although they have certain drawbacks, they are used in this section and are briefly reviewed at this time.

Underwater explosions are classified as surface (near-surface by Swift and Young), very shallow, shallow, deep, and very deep. Further, consideration should be given to extremely deep explosions for which the suppression or containment of the hydrodynamic and radiological effects is possible. Classification of underwater bursts as functions of yield and depth of explosion is then as follows, where W is the yield in KT and d the depth in feet:

Surface	$0 < d < 21W^{1/3}$
Very Shallow	$21W^{1/3} < d < 75W^{1/3}$
Shallow	$75W^{1/3} < d < 240W^{1/4}$
Deep	$240W^{1/4} < d < 600W^{1/4}$
Very Deep	$600W^{1/4} < d$
Extremely Deep	$600W^{1/4} <<< d$

Figure 11.2:3 illustrates these classes (with the exception of the extremely deep category) over a yield range of 1 to 100 KT, as taken from Huebsch (1963a).

SURFACE BURSTS

A surface burst is defined as being so shallow that the water above the charge is vaporized by the explosion. Unfortunately, the phenomena of this type of burst are not well understood. There is no question, however, that the bubble products including the radioactive debris are ejected into the atmosphere. Discussion of this phase of the transport phenomena is therefore covered in those sections dealing with the atmospheric distribution.

VERY SHALLOW BURSTS

In a very shallow explosion, Crossroads-Baker being the classical example, the bubble expands through the sea-air interface well before reaching maximum radius, while the bubble pressure is greater than atmospheric. Instabilities on the bubble periphery cause the bubble envelope to rupture, and blow-out of the fission products into the atmosphere occurs. The fraction of the radioactivity that blows out is not known. However that fraction remaining in the underwater cavity is subsequently made airborne by an upward collapse of the cavity which ejects that fraction of the radioactivity into the lower atmosphere as well. Perkins (1963) has defined this latter phenomenon as late emission.

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Fig. 11.2:3 Classification of Bursts by Yield and Burst Depth

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Scaled one-pound models of very shallow explosions suggest a more complex sequence of events, including blow-out followed by blow-in, as discussed below.

SHALLOW BURSTS

Shallow explosions are defined as those whose bubble breaks the surface during the first cycle* at times when the internal bubble pressure has dropped to or below atmospheric pressure. This depth range includes Hardtack-Umbrella at its shallow limit, wherein the top half of the bubble expanded well above the original air-sea interface but did not blow out. The interesting phenomenon of reversal of the upward motion of the upper half of the bubble envelope took place in this case. This "blow-in" phenomenon, a result of pressure differences, has been observed to create an energetic downward jet into the water on one-pound high-explosive shots scaled to this and to the very shallow depth ranges. This jet penetrates the lower half of the bubble, and should the same phenomenon take place at nuclear yields, one might expect scavenging of the radioactivity by the jet into the water below the bubble. It is not known whether this indeed takes place at high yields and for this discussion it will be assumed that all of the radioactivity is finally ejected into the atmosphere by the collapsing bubble cavity. A detailed dicussion of this interesting possibility will be presented in the sections describing the above-surface history of the radioactivity.

DEEP BURSTS

Explosions in the deep depth range include those whose primary underwater hydrodynamic transport involves bubble migration. The internal pressure of the bubble after it has reached maximum expansion has dropped well below ambient hydrostatic pressure. Then the bubble recompresses and the pressure increases to well above ambient. As the bubble oscillates, it migrates toward the surface. Snay (1960) has evaluated these hydrodynamic transport mechanisms as a function of bubble energy and suggests that the nuclear bubble will experience a maximum of three oscillations prior to breaking up. For bursts in this and deeper ranges, the bubble products can be deposited in the surrounding water during the underwater migration phase. It seems reasonable to assume that radioactivity is lost from the bubble at bubble recompression, for unequal hydrostatic pressure causes the bubble envelope to collapse in a nonspherical manner, with the bubble bottom collapsing before the top. This asymmetry, as well as surface instabilities, is thought to cause mixing with the surrounding water and the consequent ejection of a fraction of the radioactivity from the bubble. Evidence from Shot Wigwam as

*Bubble oscillation and migration will be discussed in some detail in the sections that follow.

described by Isaacs (1962), and by Folsom (1956), and preliminary experimental work with scaled explosions by Buntzen (1964) and expanded upon by Pritchett (1966), suggest this to be the case. The quantity lost during each bubble minimum has not been measured, however, and only qualitative estimates can be made.

The radioactivity released to the sea will undergo further translocation depending upon the depth at which release takes place and the stability of the ocean. Some vertical transport can be envisioned because of the hydrodynamic flow created by and surrounding the migrating bubble. If this flow does not carry the products to the surface they will come to rest, and depending on the vertical stability and the horizontal diffusive properties of the ocean, will further mix in either or both directions.

Hardtack-Wahoo and Shot Sword Fish were nuclear explosions in this depth category. However in both cases it is believed that the bubbles did not complete their first cycle prior to reaching the sea-air interface. It is thought that they reached maximum expansion below the surface and upon recompression and migration, ejected the contained radioactive debris into the atmosphere through the mechanism of strong bubble bottom collapse with oceanic contamination taking place after the plumes containing the bubble products fell back into the surface water.

VERY DEEP BURSTS

This extension of the deep category is defined as that in which the bubble breaks up prior to reaching the surface. As expressed above, the minimum depth for this range is that in which the bubble completes three oscillations on migrating to the sea-air interface. Fission product loss from the bubble as it migrates to the surface is as discussed above in the section on deep bursts. After bubble break-up, continuing hydrodynamic flow may take place and carry the residual bubble products to the surface, as is thought to be the case for Shot Wigwam. Snay's model for this explosion suggests a vortex ring developing, by which the products were carried to the surface and into the atmosphere.

EXTREMELY DEEP BURSTS

It is possible that a nuclear weapon could be exploded so deep that there would be little or no interaction of the residual bubble with the sea-air interface. Several phenomena must be considered if transport of radioactivity to the surface waters and the atmosphere is to be evaluated from this point of view of complete suppression or containment. The state of the art at this time prevents us from reaching a conclusion

with respect to the possibility that this will happen; however the governing mechanisms are understood and are considered below. Two transport mechanisms must be considered: hydrodynamic flow and buoyant transport of gases.

If one assumes that after three bubble oscillations the bubble breaks up, having given the majority of its energy to the surrounding water, then any further upward motion of the particulate and soluble radioactivity will be determined by the mass motion of the water. As stated earlier, it has been suggested that at Wigwam a strong hydrodynamic flow carried the bubble products from the point of break-up to the surface - a distance of some 800 feet was estimated by Snay (1960). Regardless of the mechanism involved, any upward flow of water is doing work against a stability barrier, and for a deep enough detonation the flow energy would be dissipated and the majority of the fission products and induced radioactivity come to rest at a depth below the mixed surface layer. However some 10 percent of the fission product radioactivity over the first 24 hours is in the form of the noble gases krypton and xenon.

The history of this gaseous component must be evaluated separately. Although these fission products amount to only several liters of gas at standard conditions, regardless of depth of burst this fraction might reach the surface and enter the atmosphere. Such transport would be assisted by any carrier gas accompanying the bubble products. For example, carrier gases might come from the high-explosive component of the weapon, dissociated water formed at the time of detonation that did not recombine, and any dissolved gases in the seawater that were taken out of solution and did not redissolve. This problem has not been studied quantitatively nor have satisfactory determinations been made on the solubility of the rare gases in seawater as a function of depth or of the existing degree of their saturation in the oceans. In summary, for the radioactivity from an extremely deep explosion to be completely contained all hydrodynamic flow must be dissipated and the gaseous component dissolved before reaching the surface.

SUMMARY

The underwater history of the radioactivity is clearly a function of the scaled depth of burst, the quantity available to the atmosphere and to the mixed layer of the ocean being dependent upon that which is trapped in the deeper waters. Table 11.2:2 lists a selected number of shot depths in an attempt to indicate the range of loss of radioactivity to the ocean during the underwater history of the bubble and the associated hydrodynamic flow. It should be emphasized that in all but the extremely deep range the surface layer of the ocean becomes highly contaminated by the mechanism of collapse of the above-surface phenomena,

TABLE 11.2:2

Summary of the Underwater History of the Radioactivity From a 10-KT Weapon as a Function of Various Depths of Burst

Depth Range	Selected Depth (ft)	Estimated Fraction of Total Radioactivity Unavailable to the Atmosphere and Surface Waters	Transport Time to Surface (sec)	Relative Decay Factor During Transport	Remarks
Surface	0	0	0	1	Immediate interaction with atmosphere.
Very shallow	60	0	~ 0.01	1	Bubble expands into atmosphere and blows out.
Shallow	180	0	~ 0.3	1.3	No blowout.
Deep	500	~ 0.2	~ 6.0	10	Surface interaction prior to or at first minimum.
Very deep	1,500	~ 0.6	~ 10	18	Bubble break-up; strong upward flow.
Extremely deep	5,000	~ 0.9-1.0	>> 10	>> 18	Possible complete suppression of hydrodynamic flow, and gas containment.

which returns the ejected radioactivity from the atmosphere to the sea. This aspect of the history will be discussed in detail in the forthcoming sections.

It is not known whether changes in underwater transport are a continuous function with depth or whether they are a step function. For example, the transitions from shallow to deep and from deep to very deep are not well understood. And one cannot conclude for example, that a burst depth from which the bubble experiences two oscillations will leave less activity underwater than that left at Wigwam where the bubble was thought to break up after three cycles.

11.2.4 THE EARLY ABOVE-SURFACE PHENOMENA AND THEIR ASSOCIATED RADIOACTIVITY

Gamma radiation from an underwater nuclear burst will interact with the atmosphere as soon as the fission products and induced radioactivity are no longer shielded by the seawater. For a surface burst this happens immediately. For very shallow and shallow bursts it happens as a function of time after burst depending upon the rate of expansion of the bubble into the atmosphere; for deep and very deep explosions, its time of occurrence depends on the migration time.

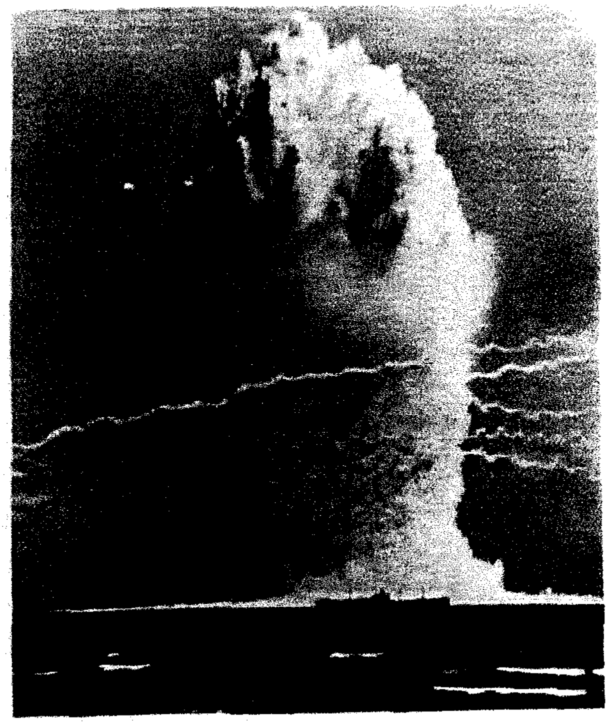
Any source of fission products above the surface will emit gamma radiation, the gamma ray transmission being a function of a number of variables, which will be discussed in section 11.3.1.

Since the early above-surface phenomena depend upon the scaled depth of burst they will be discussed in terms of the depth categories as defined earlier. In general the ejection of fission products is associated with a rising mass of water which soon collapses to form the familiar base surge. In this section the discussion will be limited to what is defined as the early above-surface phenomena, namely those atmospheric interactions preceding the formation of the base surge (see Fig. 11.2:4).

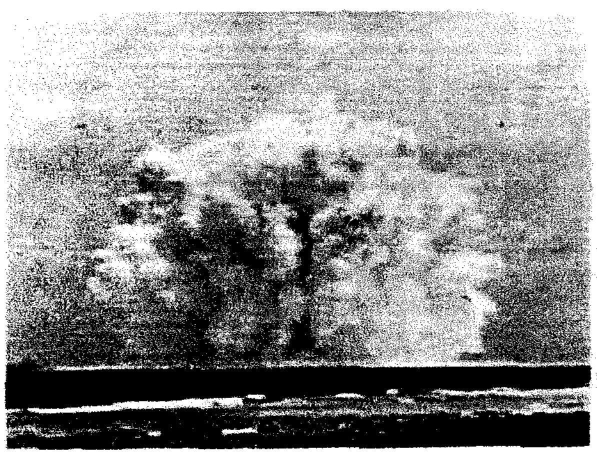
SURFACE BURSTS

This depth category considers the true surface burst; little is known about the development of its above-surface formation. The two opposing schools of thought are as follows: (1) the event will have the characteristics of a land surface burst, with a rising fireball and subsequent debris distribution by a fallout mechanism; (2) the explosion will interact strongly with the sea-air interface, creating a large underwater cavity and consequently a well-developed column of water in the atmosphere, which will fall back and create a base surge. This latter concept is characteristic of a very shallow burst. These opposing

A. Very Shallow Explosion
(Crossroads Baker)



B. Shallow Explosion
(Hardtack Umbrella)



C. Deep Explosion
(Hardtack Wahoo)

D. Very Deep Explosion
(Wigwam)

Fig. 11.2:4 Early Above-Surface Phenomena as a Function of Scaled Depth of Burst.

viewpoints will not be resolved until more theoretical work and preferably a nuclear test is accomplished. Such an event, at yields above 50 KT, might reasonably be assumed to produce above-surface effects related to those of the surface land explosion; at yields of 10 KT or less such an event might be assumed to produce above surface effects related to those of the very shallow underwater explosion.

The fact that the weapon will be exposed to the atmosphere suggests that the true surface burst has several unique characteristics as opposed to all underwater bursts. Since complete neutron absorption and gamma ray attenuation require several feet of water, a surface burst is unique in that a portion of the neutrons are available to interact with the atmosphere. Such interaction produces, in addition to the neutron flux, gamma rays resulting from inelastic scattering of the neutrons and nitrogen-capture gamma rays which contribute to the atmospheric radiation.

As the scaled depth increases in this depth range the phenomena rapidly approach those of the very shallow range, as discussed below.

VERY SHALLOW BURSTS

The early above-surface phenomena from very shallow explosions are characterized by the immediate formation of a column which rises into the atmosphere and is topped by a crown of greater horizontal dimensions. The phenomenon observed was given the name "blow-out," and the internal hydrodynamics which produce it may be described as follows: The explosion bubble upon expansion, creates an underwater hemispherical cavity, the associated flow creating the column walls. Since the scaled depth is much shallower than one maximum bubble radius, the upper half of the bubble envelope rapidly expands into the atmosphere within the column walls, and because of instabilities in the thin sheet of water above the bubble, a fraction of the bubble products blow out through the column top to form the characteristic crown. This blowout occurs because the instabilities occur while the internal pressure of the bubble is well above atmospheric pressure. Such column-crown formation has been observed both with high-explosive charges over a wide range of yields down to less than one-pound and with the nuclear test Crossroads-Baker.

A mathematical model of the bubble motion,* developed by Hammond (see Young and Hammond (1964)), considers the variation in hydrostatic pressure around the bubble envelope. This model has been found to adequately predict the envelope motion over the high-explosive and nuclear yield ranges, when compared to experimental data. It is useful in

*Suggested by Ksanda of NRDL.

evaluating the early above-surface phenomena. Of special interest is the employment of Hammond's (1965) bubble period ratio, as an equivalence criterion for scaling. It has application over all scaled depth-ranges; however it is pertinent to discuss it at this time. This concept evaluates the ratio of the periods of the top and bottom of the bubble during its first half cycle. When this ratio is plotted as a function of scaled depth for a wide range of yields and for various atmospheric pressures and gravitational fields, the areas of scaling applicability and limitation can be determined. Figure 11.2:5 shows such curves developed for a standard atmosphere and unit gravity. Further, qualitative information can be obtained in evaluation of explosions near the surface. At the 10-KT yield, for example, a Crossroads-Baker scaled shot in a bottom-free environment should experience bubble top reversal after blow-out, with the explosion products in the column returning into the still-expanding underwater cavity. This indeed was found to take place at the 1-pound yield, as discussed below.

Analysis of residual radioactivity measurements made by Strope (1963) on the Crossroads-Baker data suggests that the crown contains a large fraction of the fission products. Kaulum's (1965) measurements of the internal constituents of the column and crown from one-pound high-explosive models in the very-shallow-scaled depth range suggest a somewhat different, more complex internal structure of the column and crown. Kaulum sampled the time-space distribution of a radioactive tracer placed at the center of the charge through fixed high-speed above-surface samplers located above the point of explosion. He constructed histories of both the ejected water mass and the traced explosion products. Extrapolation of these results to the nuclear yield range would suggest that for very shallow explosions in deep water, a small fraction (less than 5 %) of the explosion products finds its way to the crown and that the flow reverses within the column as the bubble pressure drops below atmospheric, driving the explosion products underwater into the bubble cavity (see Fig. 11.2:6). This descriptive illustration points out three phases of transfer of the bubble products to the above-surface phenomena. Phase One occurs early and is characterized by the transfer of the core of explosion product to the crown. Phase Two, somewhat later, involves transfer by the converging column walls into the central jet (see below). Phase Three is described as the ejection of the residual explosion products from the bubble cavity by the process of cavity collapse (late emission).

DELETED DOE

Further experimental work is underway by Kaulum at the one-

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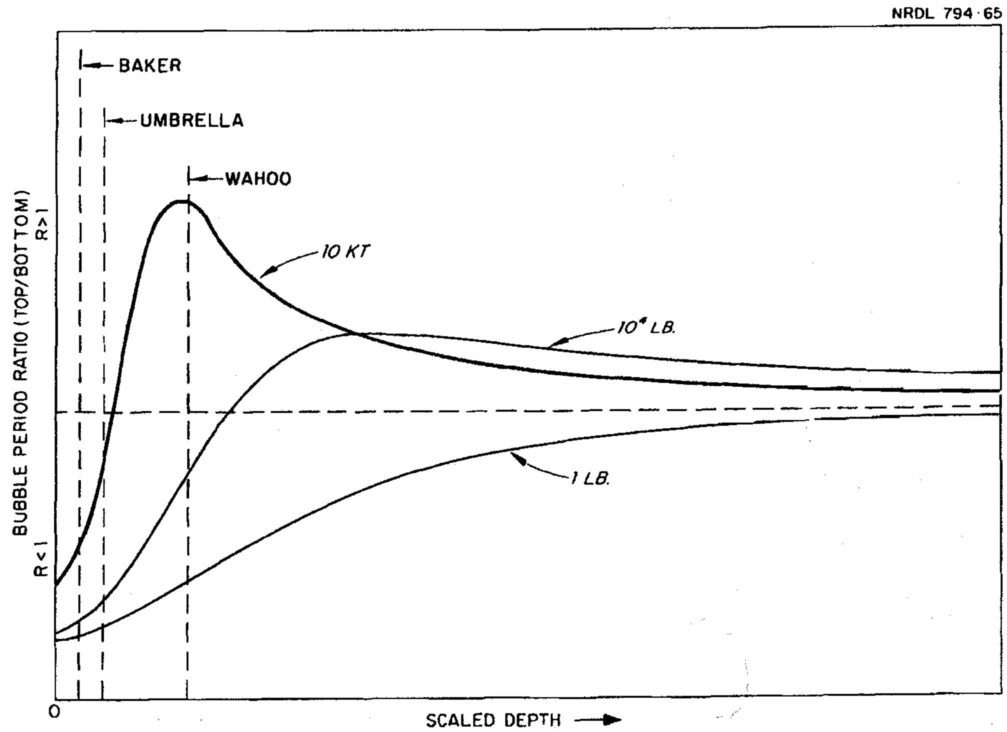

Fig. 11.2:5 Bubble Period Ratio

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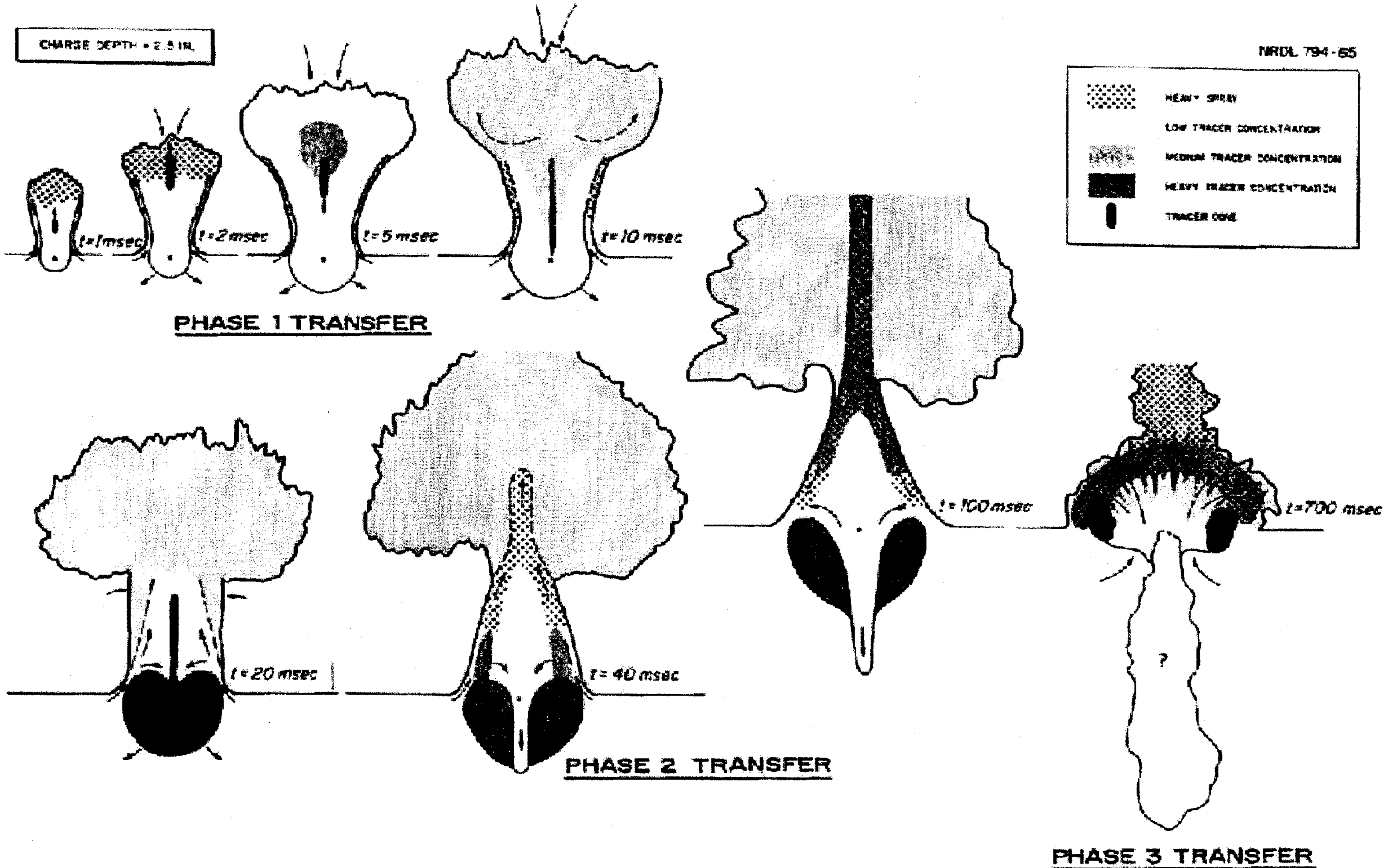

Fig. 11.2:6 Internal Column Dynamics for a 1-Pound Very Shallow, Traced, High-Explosive Underwater Detonation.

pound level to evaluate explosion-product distribution when the explosion occurs under the influence of a nearby bottom. Other qualitative evidence in this interesting area was obtained at Hydra IIA at which 10,000-pound, traced HBX-1 charges were fired in a bottom-free environment at the Baker-scaled depth, as reported by Gurney and Killeen (1964). These data show that at this yield a significant, if unknown, fraction of the explosion products found their way to the crown formation.

Projection of results from 1-pound underwater bursts to the nuclear range leads one to speculate that, for this scaled depth range, the quantity of fission products in the crown is related to the proximity of the bottom or it is yield-dependent, or both. A secondary phenomenon observed during the development of the column and crown is the "central jet," which appears to be strongly yield-dependent. This jet penetrates the center of the crown and energetically reaches great heights for low-yield charges. It is well defined at the one-pound yield range (see Kaulum (1963), observable and degraded at the 10,000-pound yield range, and just visible at Crossroads-Baker (see Young 1965a)). Again, Kaulum's work at low yields shows this jet to result from the rising water converging just ahead of the bubble envelope. At the measured yields it played an insignificant role as a carrier of explosion products.

After the column and crown stabilize, several additional flow patterns take place prior to and during the development of column and crown subsidence and the formation of the base surge. Crown subsidence is yield-dependent and for a nominal-yield weapon the crown rapidly subsides, with great plumes of water and debris being deposited at the surface. For lesser yields, at least at the 10-ton nuclear-equivalent, crown subsidence is much less energetic, with little if any of the crown reaching the surface. Further, while the above-surface phenomena are developing, the underwater cavity formed by the bubble expands to a maximum and then collapses upwards, ejecting any contained fission product material into the atmosphere at the base of the column. Perkins (1963) observed this phenomenon at Hydra IIA and associated it with the similar phenomenon observed by Hendricks (1960) at Hydra I, which Hendricks called "late emission." Late emission and possibly crown collapse play an important part in the contamination of the base surge, as will be discussed in a following section.

Considering, with bubble theory, the above, rather complex series of events prior to the formation of the base surge, it is possible to estimate the fate of the fission products and to generate gamma exposure rate fields described as initial radiation. Accomplishments to date in this area of exposure rate calculations will be discussed in section 11.3.2.

In summary, for very shallow bursts it is felt that the quantity of radioactivity in the crown is highly dependent upon the proximity of the bottom and may be yield-dependent. The primary sources of fission product debris above the surface at early times are first the crown and then the late emission. Both contribute to later contamination mechanisms.

Transition to the shallow scaled depth range is indicated by reduction in the magnitude of the crown.

SHALLOW BURSTS

The early above-surface phenomena from shallow explosions are similar to those from the very shallow case, with the important exception that no crown is formed at the column top. The state of the art suggests the internal column hydrodynamics may be similarly described. However because of the greater scaled depth, blowout does not occur, because the bubble pressure drops below atmospheric before the envelope can rupture. Consequently, the fission products that initially rise with the expanding bubble are reversed and driven underwater within the column, residing in the expanding underwater bubble cavity (no Phase One transfer).

DELETED DOE

Also, as discussed earlier, positive evidence of absence of blow-out at this scaled depth was observed by Kaulum (1965) with traced one-pound charges and the sensitivity of transition from very shallow to shallow scaled depths was observed by Gurney and Killeen (1964) with traced 10,000-pound charges. The high-explosive work was done in a bottom-free environment, which suggests that the transition depth from blow-out to blow-in for the nominal-yield nuclear device may be insensitive to bottom proximity.

Again as in the very shallow case, the central jet acts in a similar manner; however Phase Two transfer may be considered negligible.

Since essentially all of the activity is confined to the underwater bubble cavity for the shallow situation, the first major permanent appearance of radioactivity in the atmosphere is caused by late emission. It is considered the primary mechanism for contamination of the base surge, as will be discussed later.

DEEP BURSTS

The transition from shallow scaled depths to deep scaled depths must be gradual, with a general degradation of the column formation until the explosion depth is reached for which the bubble's first expansion takes place entirely underwater. At this point the above-surface

~~SECRET~~
~~RESTRICTED DATA~~
[redacted]

phenomenon has completely changed from a columnar to a bushy plume-like formation. This change results from the bottom collapse of the expanded bubble through the bubble top into the atmosphere. This bubble inversion results from the strong differential hydrostatic head across the vertical bubble diameter. As the bubble contracts and collapses, essentially all of the fission products are ejected into the atmosphere with large quantities of water, which then fall to the surface and propagate as a base surge. At these scaled depths and deeper, the acceleration of gravity plays an important part in bubble motion. Consequently, simulation with low-yield high-explosives is less reliable in a natural environment because of the gravity constancy.

DOE

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Results of interest to the problem of radiological effects can be found in Evans and Shirasawa (1962) and in Egeberg (1963), respectively.

In this deep range, bubble migration varies from minimal, as was the case for Hardtack-Wahoo and Sword Fish, to that seen at scaled depths at which a number of bubble oscillations are experienced prior to any surface interaction. This portion of the deep range, where oscillation and migration take place but prior to bubble break-up, requires further discussion. First the best evidence suggests that with each bubble minimum, instabilities arise that permit ejection of the fission products to the surrounding water. A mechanism for this process has been suggested by the experimental work of Pritchett (1966). There seems to be ample theoretical reason to believe losses do take place at bubble minima. However the ultimate fate of the lost products is in question. Assume that at each minimum a fraction of the fission products are ejected into the surrounding water. Their final rest point should be dependent upon the hydrodynamic flow surrounding the bubble as it migrates towards the surface. A strong flow would carry the material upward with the bubble and it would be ejected into the atmosphere. A weak flow would allow the material to be trapped in the lower layers of the ocean, unavailable to the atmosphere. Unfortunately no data exist in this region of the deep range and further theoretical work is required.

As the bubble migrates toward the surface the geometry of the above-surface event may be related to the bubble phase as it interacts with the sea-air interface. Perkins (1963) obtained evidence of this at Hydra IIA, and it was previously suggested from analysis of past data by R. Shnider of NRDL.* It is known however that throughout the deep range there will be a strong ejection of water and fission products into the atmosphere, with the subsequent development of a base surge.

*Private communication.

[redacted]

VERY DEEP BURSTS

As defined earlier this depth range is defined such that all explosions within it generate bubbles which ~~experience~~ three oscillations and break up ~~before reaching~~ the surface. DOE

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He further suggested that a vortex ring developed from this point on, which carried the residual bubble products to the surface. Even at this depth a strong energetic plume was observed in the atmosphere, with the subsequent development of a base surge. Folsom (1956) and Isaacs (1962) investigated the subsurface layers of the ocean after the Wigwam event and concluded that a substantial fraction of the fission product debris had been trapped in the thermocline layer. Isaacs's integration of the measured radioactivity indicated that some two-thirds of the total equivalent fissions produced were in the waters beneath the mixed layer. Unfortunately these data were obtained several days to several weeks after the detonation and do not permit one to conclude whether this debris was left behind by the bubble or whether it followed the bubble to the surface and later sank to a depth consistent with its own density.

EXTREMELY DEEP BURSTS

This depth category can be considered an extension of the very deep range, wherein the scaled depth is so great that the above-surface phenomena are suppressed and the fission products are essentially contained in the sea below the mixed layer. For this to occur, the bubble energy has to be dissipated, and all hydrodynamic flow has to cease such that subsurface water cannot carry a fission product to the surface layer. For complete containment, all gaseous products would have to be prevented from reaching the surface, by going into solution. Very little research has been done on this problem.

11.2.5 THE BASE SURGE

The gravity collapse of the column (supplemented by the late emission water mass for very shallow and shallow-scaled depths) or plume (for deep bursts) described above generates a dense aerosol cloud at the surface, the base surge, which expands radially at high speeds as long as energy is available from the subsiding water mass (see Fig. 11.2:7). All underwater nuclear tests have produced this phenomenon, as have high-explosive underwater tests for yields as low as 100 pounds TNT-equivalence. Young (1963) investigated the hydrodynamics of the base surge. It can be concluded that the aerosol configuration and dimensions during initial expansion are functions of the scaled depth of burst. In all cases, after complete collapse of the energy source (column or plume), the base surge continues to expand as an annulus, eventually coasting to a stop and drifting with the wind. Since the cloud is essentially

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Fig. 11.2:7 Typical Base Surge
(Shot Sword Fish)

a dense seawater aerosol, its history is a function of the local meteorological conditions, and in general the surge evaporates as it is carried along the surface with the wind. Evidence from the Crossroads Baker test suggested to Young (1965a) and other investigators that the base surge from this event rose from the surface and had the appearance of low stratiform clouds in its later stage of development from which rain was observed to fall. However, this phenomenon should be considered unusual. Other possible meteorological environments such as arctic climates, have not been studied. They could conceivably be important in affecting base surge transport. Evans (see Evans and Shirasawa (1962)) suggests, from nuclear test data, that the base surge in a temperate climate is a transiting phenomenon, depositing an insignificant fraction of the aerosol on the surface. However Sword Fish data reported by Egeberg (1963) suggested the possibility of rainout from the surge at early times. A droplet coalescence model of the base surge, developed by Ulberg (1963) was tested against Sword Fish data. Ulberg concludes that rainout does indeed take place, but at very early times and within a few thousand feet of the explosion axis for a nominal-yield device.

It is well known that the base surge is a major carrier of fission product debris for most scaled depths of burst and consequently is the most important atmospheric radiological hazard to surface ships. The contaminating mechanism of the base surge aerosol is complex and not completely understood.

SURFACE BURSTS

As stated earlier, little is known of the above-surface phenomena from a nominal-yield true surface-burst over deep water. Conflicting arguments suggest that (1) energy coupling to the sea will be negligible and the event will have the characteristics of a land-surface nuclear explosion, with a rising fireball and resultant fallout, or (2) energy coupling will be significant as it is in high-explosive water-surface bursts, with development of a column and crown much like the above-surface phenomena from a very shallow underwater explosion. Data from past nuclear tests suggest case 1 to be valid for high-yield devices; at Operation Redwing no base surges were formed. Should case 2 be valid at lower yields, one would expect base surge characteristics as discussed below for the very shallow scaled depth range.

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VERY SHALLOW BURSTS

Upon analyzing meager radiological data at Crossroads-Baker, Strope concluded that the initial base surge aerosol was uncontaminated and the major surface contamination resulted from the subsidence of highly contaminated material from the crown (see Fig. 11.2:8). Evidence from other work, as described by Kaulum (1965) from low-yield high-explosive data, suggest that base surge contamination evolves from ejection of fission products (late emission) at the column base shortly before column collapse, especially for a very shallow explosion in a bottom-free environment. Regardless of the mechanism of injection of fission products, the base surge can be considered as a carrier of a fraction of the fission products.*

SHALLOW BURSTS

In this depth range blow-out does not take place and it is estimated that all the fission products enter the atmosphere through late emission or underwater bubble cavity collapse at the column base just prior to column collapse. The efficient mixing of ejected fission products with the subsiding column aerosol droplets associates a fraction of the products with water droplets which are immediately deposited in the surface water, with the remainder being uniformly mixed with the base surge carrier aerosol. This mixing leads to fractionation of the fission product mixture, which will be discussed later.

DEEP AND VERY DEEP BURSTS

During bubble migration within these depth ranges, some of the fission products are ejected into the surrounding water along the bubble migration axis. These products are either carried with the bubble flow or left behind in the thermocline layer of the sea. However throughout these depth ranges the related above-surface phenomena, as described earlier, can be considered to consist of the eruption of bushy plumes into the atmosphere. These are uniformly contaminated with fission products, and their collapse creates a uniformly contaminated base surge.

*Recent work by Young (1965b) on a thorough analysis of Crossroads Baker data suggested to him two base surge formation processes separated slightly in time. For this shot he argues that the late emission forms the primary contaminated base surge, followed by a secondary surge from the column collapse, which is essentially uncontaminated. As opposed to Young, the author suggests a much stronger interaction of the collapsing column with the late emission for nominal yield very shallow and shallow bursts and uses this mixing process to suggest a fractionation mechanism. However, where column collapse is weak, as discussed later for low yield explosions (less than 0.1 KT), the phenomenon described by Young is evident.

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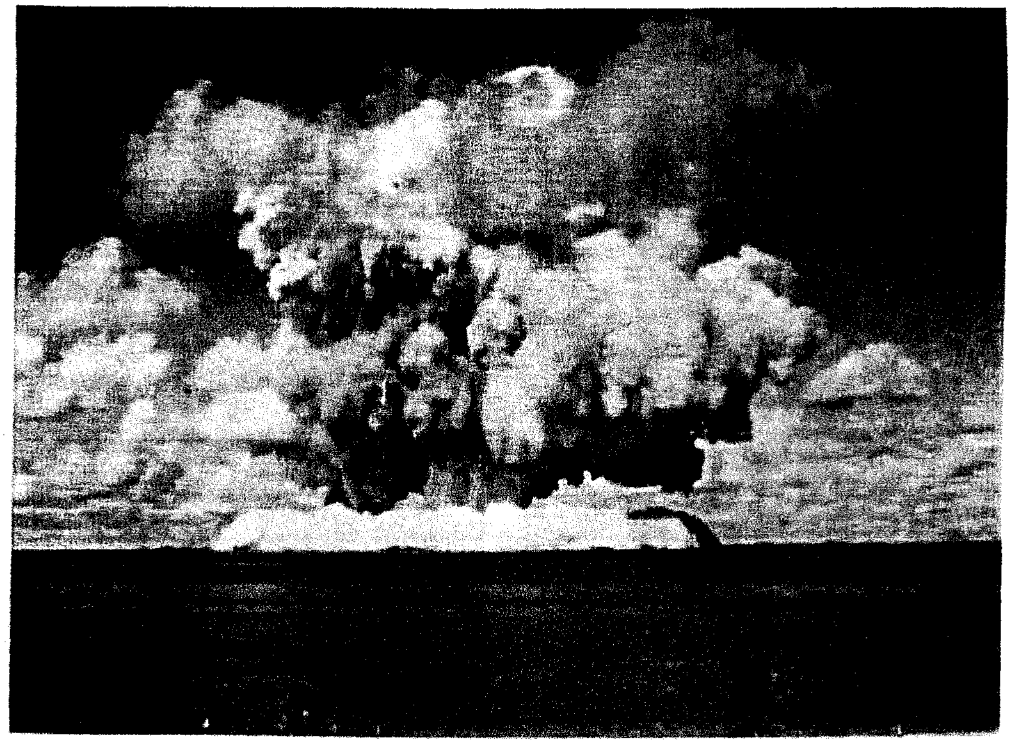

Fig. 11.2:8 Crown Subsidence as Observed at Crossroads-Baker

Again, a fraction of the plume and associated fission products are immediately returned to the sea, with the remainder associated within the base surge. Although fractionation of the fission products does take place (see below) it should not be as pronounced as that in shallow bursts because of the hypothesized less efficient scrubbing action occurring with plume collapse as compared to the interaction of the subsiding column and late emission mixing described above.

EXTREMELY DEEP BURSTS

By definition no base surge will form from explosions detonated within this scaled depth range.

FRACTIONATION OF THE BASE SURGE FISSION-PRODUCT MIXTURE

Evidence from samples of base surge radioactivity from nuclear tests (see Evans and Shirasawa (1962)) suggests that the base surge does not carry all fission products (or their daughters) formed at the time of detonation but rather that the mixture is depleted of refractory products to a degree depending upon the scaled depth of burst. This fractionation of the original fission product mixture may come about by the initial interaction of the fission products with the column or plume droplet aerosol. Caputi (1960) considered the collection efficiencies and activation energies of particulate and gaseous constituents with respect to droplets, and suggested that the particulate or refractory fission products should be efficiently collected by the base surge aerosol, whereas the gaseous products should be collected in an inefficient manner. This study agrees with a possible explanation of the fractionation mechanism wherein the refractory products are considered scrubbed and returned to the sea when the base surge is formed, leaving the gaseous products to be carried with the surge aerosol, interspaced between the surge drops. One may conclude that the fraction of the total equivalent fissions produced that exist in the base surge is dependent upon the degree of fractionation, which in turn is related to the scaled depth of burst. For example, the base surges from very shallow and shallow bursts should be more highly fractionated than those from deep and very deep bursts, if the efficiency of scrubbing of the products to the sea is an acceptable hypothesis.

11.2.6 RESIDUAL RADIOACTIVITY IN OCEAN

During the dynamic phase of an underwater nuclear explosion some of the radioactivity produced is either left behind in the seawater or is returned to the surface waters with the collapse of the column, crown, or plume. Further, some small fraction of the base surge radioactivity is deposited in the surface water. That fraction deposited beneath the mixed layer, from deep and very deep explosions, presents no hazard at the surface; however the contamination of the mixed layer of the ocean constitutes a severe hazard to surface ships shortly after detonation.

Observations at past underwater nuclear weapons tests and at tests employing high-explosives as models have shown the existence of an outward radial flow of the surface waters from surface zero shortly after detonation. This hydrodynamic flow is visible as an expanding patch of white foamy surface water (see Fig. 11.2:9), and for nominal-yield weapons its rate of expansion during the first hour is more rapid than can be explained by horizontal diffusive processes. For yields in the fractional kiloton range this explosion-driven circulation lasts for approximately one-half hour. J. Pritchett* has developed a physical model relating the pool development to scaled depth of burst. Ksanda (1963) has evaluated later-time pool growth and has calculated the pool's horizontal extent as a function of time, based on a concept of horizontal eddy diffusion. Both models rely on nuclear test data, with the best surface pool information at early times being reported by Shirasawa on Shot Sword Fish.

A question yet to be resolved is the mechanism by which the pool becomes contaminated at early times, the primary unknown being the pool's initial depth of contamination. Field test data (see Shirasawa) indicate that at several hours post-detonation the radioactivity is mixed throughout the surface (mixed) layer and does not penetrate into the thermocline layer. Calculations of the pool intensity during the first hour require assumptions with respect to the rate of vertical mixing during the dynamic phase of pool development. If it is assumed that the radioactivity is initially delivered to the water surface with the collapsing column, crown, or plume, a model can be developed assigning all of this debris to the white patch, extending in depth just a few feet. Rapid vertical mixing would then carry the debris downward during the first hour. This process, as opposed to that which introduces the debris immediately throughout a substantial depth, would result in extremely high dose rates during the first half hour post-detonation.

The residual radioactivity in the surface layers has been followed after a number of nuclear tests for periods of from days to weeks. Radioactive decay and expansion by horizontal eddy diffusion rapidly reduce the hazard. Wesley, et al (1963), report aircraft radiation surveillance of the radioactive pool from Shot Sword Fish for a period of one week. Beyond a few days, the distribution of radioactivity is of interest primarily in relation to contamination of marine organisms and to detecting clandestine underwater nuclear testing.

For deep and very deep explosions, where the bubble experiences several oscillations as it migrates toward the surface, radioactivity may be ejected from the bubble at minima as discussed earlier. Measurements at Operation Wigwam by Folsom (1956) and Isaacs (1962) indicate that there are both a radioactive surface pool and random lens-like pools of debris in the thermocline layer. These deep pools were measured some

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*USNRDL report to be published.

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6.3 MINUTES

Fig. 11.2:9 Typical Early Pool Development (Sword Fish)

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days after detonation and were found to be small and quite stable. Whether these deep deposits represent radioactivity that was left behind by the migrating bubble or material carried to the surface by hydrodynamic flow and returned to its original stability level, is not known. No such lamina have been observed at other underwater nuclear tests, perhaps because no determined search was made.

11.3 PREDICTION OF ATMOSPHERIC GAMMA RADIATION FIELDS *

Estimates of the sources and mechanisms of contamination as described above permit delineation of the spatial history of the fission products which produce the gamma radiation fields in the atmosphere. Any prediction system requires that the locations, strengths, and configurations of these sources be known as functions of time. Further, a computational model is required to calculate the photon history within the space of interest. It will become evident in this section that not all of the required inputs for an accurate prediction system exist. Therefore, many assumptions are required.

The principal sources of fission products contributing to atmospheric radioactivity have been defined. These are (1) the initial radioactivity associated with the rising columns and plumes prior to the formation of the base surge, (2) the base surge, and (3) the residual radioactivity in the surface layers of the sea. It now becomes necessary to assign to these sources quantities of dimension and intensity as functions of time. This would permit use of gamma ray transmission theory to estimate the exposure rate fields throughout the space of interest.

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*Computerized prediction models are presently being developed at NRDL to describe this entire phenomena. These studies will be published in two reports as follows:

(1) Young, F.H., et al, "A Monte Carlo Gamma Exposure Rate Computation Model for Nuclear Weapons Effects Studies (U)."
(2) Schuert, E.A., et al, "DAEDALUS - A Gamma Exposure Rate Prediction Code for Underwater Nuclear Bursts (U)."

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11.3.1 GAMMA-RAY TRANSMISSION THEORY

A fission-product source emits gamma rays over a wide range of energies from approximately 0.25 to 6 Mev. Gamma ray energy spectra are available as a function of time for unfractionated mixtures and can be estimated for fractionated mixtures and for the additional contribution from induced products.

The history of each photon depends upon its initial energy and the medium through which it travels. Each photon may experience a number of interactions with the medium before it loses all of its energy. The major interactions include Compton scattering, with a resultant partial loss of energy to the production of a Compton electron;pair production, with the total loss of photon energy to the creation of a positron-negatron pair; and photoelectric effect, resulting in the complete conversion of the photon energy to kinetic energy of photoelectrons. With both Compton scattering and pair production the resultant secondary gamma rays may experience similar interactions, this process continuing until all residual photons experience a photoelectric interaction, thus depositing any residual energy. Each type of interaction is related to the relative magnitude of the cross-sections within the medium for that given type of interaction. Theoretical experiments have been developed to follow the history of photons in this realistic manner based on Monte Carlo calculational techniques.

More general approaches to gamma ray transmission calculations are based on semi-empirical techniques developed as follows:

For a mono-energetic point source in an infinite homogeneous medium of known cross-section

$$R = \left(K \left(\frac{\mu_a}{\rho}\right) B_x I_o e^{-\mu x}\right) / 4\pi x^2$$

Summing over an energy spectrum,

$$R = \sum_{i=1}^{n} \left[K \left(\frac{\mu_a}{\rho}\right)_i B_{i,x} (I_o)_i e^{-\mu_i x}\right] / 4\pi x^2$$

Summing over a volume source,

$$R = \sum_{j=1}^{m} \sum_{i=1}^{n} K \left(\frac{\mu_a}{\rho}\right)_i B_{i,x_j} (J_o)_{ij} e^{-\mu_i x_j} dV_j \; / 4\pi x_j^2$$

[redacted]A
[redacted]

where: R = exposure rate (r/hr)
K = exposure rate conversion constant (MEV/sec/gm to r/hr)
μ_a/ρ = energy absorption coefficient (cm^2/gm)
B = Buildup factor (dimensionless)
I_o = emission intensity (MEV/sec)
μ = linear attenuation coefficient (cm^{-1})
x = distance to detector (cm)
j_o = emission intensity (MEV/cm^3 sec)

These complex equations have been simplified by Ksanda and Laumets (1959) for an infinite air medium through the development of an effective attenuation coefficient which eliminates the need for consideration of the entire photon energy spectrum in the computations. Such empirical approaches are presently limited in that they are applicable only for an infinite homogeneous air medium.

Monte Carlo calculational techniques (see Kahn (1956)), in which a large number of photons are released from a source or distribution of sources, have the advantage that the photon subsequent life histories can be traced mathematically in a realistic manner through any medium or combination of media whose geometry and nuclear cross-sections are known. However, utilization of this technique requires a substantial amount of high-speed computer time.

Another calculational method has been developed by Spencer and Fano (1951, 1951a). This semi-numerical technique for solving the Boltzmann equation is known as the moments method. This technique has the advantage of requiring less computer time, however it is restricted in that it can handle only infinite medium problems.

11.3.2 PREDICTION OF INITIAL GAMMA RADIATION FROM COLUMNS OR PLUMES

The literature cites a number of predictions of initial radiation from underwater nuclear explosions. We discuss these in chronological order. Young (1956), employing a semi-empirical approach calculates the gamma radiation dose for explosions over a yield range of 1 to 30 KT and a depth range from the surface to 600 ft. Russell and Zirkind (1957) modify the radiological input of Young's work and predict initial gamma dose and dose rate to aircraft for an 8 KT yield over a depth range of 125 to 415 ft. Their work is extended (see Zirkind, et al (1958), to times up to 15 minutes and to include surface dose and dose rate calculations. Further, they consider yields of 2, 8, and 28 KT over the depth range from 150 to 2000 ft. Ksanda, et al., (1959) predict the initial gamma radiation dose for 10 KT and 50 KT water-surface bursts.

Rainey and Shnider (1962) predict the initial gamma radiation from a proposed series of water-surface bursts of yields including 0.1, 1, 4, and 10 MT. Various fission-to-fusion ratios are considered. Shnider (1964) calculates peak initial gamma dose rate and total dose for water-surface bursts over a range of yields, and investigates the initial gamma radiation from Hardtack Wahoo and Umbrella. The latest published work on prediction of initial gamma radiation from underwater nuclear explosions can be found in the Spin Drift Effects Handbook (1964). Here, the initial radiation is predicted for a 10-KT water-surface burst and a 0.02-KT shot at a depth of 9 ft on the bottom. Deeper fractional kiloton shots are considered; however no initial radiation is predicted.

Almost all of these works were based on very little data and were generated through simple analytical models or semi-empirical scaling techniques. Thus, discrepancies exist between the reported works; however, a general improvement in this field is evident in the later publications.

The state of the art at this time still suffers from a lack of verifying nuclear test data; however, as indicated above, some estimates can be made regarding the radiological effects to be expected from initial radiation over a range of yields and depths of burst.

SURFACE BURSTS

Knowledge of all radiological phenomena from nuclear bursts at the surface of the sea is extremely poor. Most predictions of the initial radiation from such a burst geometry have been based on extrapolations of data obtained from nuclear tests with large-yield detonations on barges over relatively shallow water. In these cases the history of the radioactive debris resembled that of a slightly modified land-surface explosion.

For prediction purposes it must be assumed that the fireball from a true surface burst will be exposed to the atmosphere and therefore the initial radiation will consist of a neutron pulse, gamma rays resulting from inelastic scattering of the neutrons, and nitrogen-capture gamma rays. This sphere of radiation will extend to an initial radius of about 6000 feet, rapidly disappear, and leave as a residual, the gamma fields generated by the fission products in the rising fireball. Given the weapon design and yield, both total and fission, one can make numerical estimates of the intensity of this radiation as a function of space and time with a reasonable degree of accuracy.

VERY SHALLOW BURSTS

The initial radiation from a very shallow underwater nuclear explosion consists entirely of fission-product gamma radiation and can be assumed to originate entirely from the crown at the column top. No reliable nuclear test data are available to estimate the fraction of the fission products making up this source of radiation. Unfortunately, scaled models suggest the mechanism of transfer to the crown may be dependent upon both the yield and the proximity of the bottom. The state of the art suggests qualitatively that the crown is the greatest source when the growing bubble interacts strongly with the bottom. An analysis of the Crossroads-Baker data led Buntzen(NRDL)* to assume that approximately 50 percent of the fission products were transferred from the bubble to the crown. Using this as a crude base point, prediction of the source strength might lower this value to 10 percent for explosions in a bottom-free environment. This rather ill-defined source of initial gamma radiation whose dimensions can be estimated from nuclear and high-explosive data, generates gamma radiation fields calculable through appropriate gamma ray transmission models. The unknown effect of gamma ray attenuation by the presence of water in the crown introduces further errors in the calculations. The life history of this source appears to be yield-dependent, with explosions in the kiloton range having crowns that rapidly subside, depositing their radioactive debris on the surface, while explosions in the sub-kiloton range produce crowns that experience negligible subsidence, with their fate influenced more by the combined effect of wind and droplet settling rates.

From the time of formation of the crown to its dissipation, it acts as a very intense source of radioactivity.

SHALLOW BURSTS

The initial radiation from shallow bursts is well understood over a wide range of yields and appears to be insensitive to bottom proximity. All nuclear data and measurements made using high explosives as models suggest that the initial radiation in this depth range is negligible. A very low short-lived burst of gamma radiation is observed as the nuclear bubble projects into the atmosphere within the column walls. However the bubble soon reverses itself, carrying the fission products below the surface into the bubble cavity, thereby effectively shielding the radiation from the atmosphere.

Initial radiation, as defined, can be ignored for explosions in this scaled depth range.

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*Private communication.

DEEP BURSTS

Bursts in the deep depth range must be considered in two groups in evaluating their radiological effects. The first includes those bursts that experience little if any bubble migration, and the second those that experience bubble minima and strong migration.

Consider the first group: Since the bubble collapse near the surface is a result of strong bubble bottom penetration (see Wahoo, Fig. 11.2:5), with the bubble cavity and its contents being ejected into the atmosphere in the form of plumes, hydrodynamic considerations strongly suggest that all of the fission products formed are mixed in the plume formation above the surface. Although these plumes rapidly subside, forming the base surge, a strong initial radiation source may exist during their erruptive phase and prior to the formation of the base surge. Limited measurments of gamma radiation at the surface from Hardtack-Wahoo and Sword Fish, both shots being of the nature described, do not support the above hypothesis that all of the fission products are initially above the surface in the plumes unless one assumes the plumes during these very early times are of such density that they act as a good shield. Nevertheless, theory permits the conclusion to be made that the plumes are a strong source of initial gamma radiation, and calculations can be made describing the gamma radiation fields about this source geometry.

For deeper bursts in this depth range, some of the fission products are thought to be ejected from the bubble at minima as it oscillates and migrates to the surface. This alone complicates the computational problems and they are further complicated by the little understood relationship of the expected above-surface effects to the phase of the bubble on reaching the surface. High-explosive data through this depth range suggest that plumes having either a columnar or bushy geometry will be produced, depending upon the scaled depth of burst. No nuclear data are available. As a best estimate, it might be concluded that the initial radiation from bursts in the second group of this depth range will be degraded in intensity below that expected from a group one explosion.

VERY DEEP BURSTS

Measurements of the residual radioactivity in the sea following shot Wigwam as well as that in the base surge suggest that, although the bubble is considered to have broken up prior to reaching the surface, the resultant plumes carried some fraction of the fission products into the atmosphere. Estimates of the quantity of radioactivity in the base surge and the mixed layer of the sea suggest the plumes could not have

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contained more than about one third of the total radioactivity formed. However if all the radioactivity found in the sea had been initially ejected into the atmosphere, a possibility, then the initial radiation might be significant. Of course, it should be remembered that the travel time of the bubble of a very deep burst to the surface is relatively long and reduces the initial fields, through radioactive decay.

EXTREMELY DEEP BURSTS

By definition no above-surface phenomena will develop from explosions in this depth range and consequently there will be no initial radiation in the atmosphere.

11.3.3 PREDICTION OF THE GAMMA RADIATION ASSOCIATED WITH THE BASE SURGE

A mathematical model of the base surge has been developed by Huebsch (1963a) for the purpose of predicting the transit radiation associated with the surge passage over the surface of the sea. Input variables to the model include weapon yield, burst depth, and surface wind speed. The model was developed from nuclear weapons test data and generalized for application over most scaled depth ranges. Idealized geometrical forms were used to represent the source of base surge radiation; it was assumed that (1) radiation is attenuated by air only, (2) the distribution of radioactivity in the radiological base surge is homogeneous, (3) there is no fractionation of the fission products in the base surge and (4) the circular plan view of the base surge is not distorted by the wind. Gamma ray transmission calculations made use of an effective attenuation coefficient developed for an infinite homogeneous air medium and a fission product gamma ray spectrum. The author states the model was developed to operate over the yield range of from 1 to 100 KT throughout the scaled depth ranges from very shallow to very deep.

Since the model development was based on nuclear test data it can be concluded that its reliability is best for those scaled depth ranges that are best documented experimentally, namely the shallow and deep ranges. Application to the very shallow and very deep ranges should be used with caution.

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SURFACE BURSTS

Lack of theoretical and experimental information on true water surface bursts has resulted in an either/or situation regarding the base surge. It will be assumed that for explosions over 50 KT total yield the above-surface phenomena will be that of a land-surface explosion with no base surge formation. For yields of 10 KT or less, it is not known whether the energy coupling to the sea will result in a burst resembling a land-surface explosion or in a very shallow underwater explosion. If it is like a land-surface burst, no base surge will form; if a very shallow underwater nuclear burst, the base surge will be as described in the following section.

VERY SHALLOW BURSTS

The collapse of the column from a very shallow burst generates a strong base surge aerosol that initially can be considered uncontaminated or very slightly so. Several contamination mechanisms are immediately apparent and probably are a function of the explosion yield. For a nominal-yield weapon the fission products can be considered transferred to the base surge from the collapse of the underwater bubble cavity (late emission) and from the collapse of the contaminated crown into the expanding base surge. The efficiency of uptake of fission products by the base surge is poorly understood for this complex situation. If, for the Baker geometry, half of the fission products are in the crown and the remainder in the bubble cavity, one might hypothesize poor uptake from crown fallout and strong fractionation of those products ejected from the bubble cavity as they are scrubbed by the subsiding column. A subjective estimate would transfer about 5 percent of the total activity to the surge, highly fractionated in favor of the noble gases and their daughters.

Considering a bottom-free environment in which the crown may be less contaminated, one would expect that perhaps 10 percent of the fractionated mixture would be transferred to the surge due to late emission. This review summarizes the poor state of the art for very shallow underwater nuclear bursts. For planning purposes, surge contamination can be assumed to be 5 percent of the fission product mixture for explosions near the bottom and 10 percent for those in a bottom-free environment.

This underwater depth range has the additional highly contaminating mechanism of crown collapse which occurs close to surface zero and in the time frame when the base surge is developing. Heavy fallout is predicted for nominal-yield bursts near a bottom, less for a bottom-free environment, and much less for fractional kiloton yields for which the crown collapse is very weak. Strope's analysis of the contamination from crown collapse at Crossroads-Baker indicated an average deposit exposure to infinity of 4000 r in an annulus several thousand feet from surface zero.

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SHALLOW BURSTS

The less complex shallow explosion depth range does not involve blow-out and the development of a crown. Again it can be assumed that the column collapse creates a strong uncontaminated base surge aerosol and that the fission products are efficiently and uniformly mixed into it through late emission. If 100 percent of the fission products are ejected by the upward collapse of the bubble cavity, the scrubbing action of the falling column water droplets will fractionate the mixture, and about 10 percent of the activity will enter the base surge. These products, which are not returned to the sea, are most probably the noble gas fission products. High-explosive model experiments and data from Hardtack-Umbrella suggest that the proximity of the bottom is not important in fission product transfer in this depth range.

As the surge expands, Ulberg (1963) estimates that a negligible amount of the fission products rain out close to surface zero, with the majority of the contamination being carried in suspension with the non-settling base surge aerosol. Adequate gamma exposure rate predictions can be made with Huebsch's mathematical model in which he best fits field data with a surge fraction equal to 10 percent of the unfractionated fission product mixture. It should be remembered that this model considers air attenuation only in its gamma ray transmission calculations, and an exact model in considering the fractionated fission product spectrum and the attenuation due to water would have a different and more exact measure of the true fraction of the weapon in the base surge. The state of the art does not permit the development of such a model at this time.

DEEP BURSTS

For those explosions in this depth range that experience little bubble migration, essentially all of the fission products are ejected into the atmosphere in the form of hemispherical plume resulting from the collapse of the bubble. As the plumes, consisting of water and nuclear debris, subside, scrubbing action is not as pronounced as it is for vertical column collapse and a larger fraction of the fission products is delivered to the base surge. The mixture in the base surge is estimated to be fractionated nevertheless, with all of the noble gases and some of the refractory products being present. Since the state of the art prevents the consideration of fractionation in a quantitative manner, Huebsch employs a 33 percent unfractionated mixture in the base surge. Although the visible base surge formed is annular in geometry, the radiation fields suggest that some of the activity is in the central void and Huebsch employs a disk geometry, uniformly contaminated, for this scaled depth range. Unfortunately no data exist for base surges in this depth range that result from explosions detonated at depths from

which the bubble oscillates a number of times prior to reaching the surface. The major un-answered question is whether the activity lost beneath the surface at each bubble minimum remains behind at depth or whether it is carried along the bubble migration axis and is ejected with the plumes.

VERY DEEP BURSTS

When the bubble breaks up prior to reaching the surface and any above-surface phenomena are the result of hydrodynamic flow of residual bubble debris, a plume can form and develop an energetic base surge. For Wigwam, Huebsch estimated on the basis of very limited data that the base surge carried about 10 percent of the bomb products. Further, Isaacs estimated some two-thirds of the bomb products in and below the thermocline layer and one-third in the mixed layer of the sea. These analyses suggest that within this scaled depth range the base surge is less radioactive than for the deep range. However even greater depths are required in order to suppress the interchange with the atmosphere.

EXTREMELY DEEP BURSTS

At some depth no base surge will form if the hydrodynamic flow along the bubble axis loses its energy below the surface. It is anticipated that this will be the case within the extremely deep depth range.

11.3.4 PREDICTION OF GAMMA RADIATION ASSOCIATED WITH RESIDUAL RADIOACTIVITY IN THE SEA

Data reported by Shirasawa (1964) on measurement of the radioactivity in the sea following Shot Sword Fish and data obtained by Egeberg (1963) for the same weapons test suggest the possibility of extremely high exposure rates from the pool at times shortly after detonation (up to H + 1/2 hour). Measurements made at later times by Wesley, et al (1963) (see Fig. 11.3:1), if projected back in time to the first half-hour post-shot, do not bear out the above-mentioned observations. These conflicting data leave open to question the radiation levels to be expected at these early times. However a model of the surface layer radioactivity history has been constructed by Ksanda (1963) for employment over the time interval from H + 1/2 hour to many weeks. This analytical technique considers the initial source dimensions, source strength, and then through processes of vertical mixing, horizontal eddy diffusion, and radioactive decay, it computes the pool dimensions and atmospheric gamma radiation exposure rates to be expected as a function of time for a wide range of yields and scaled depths.

Little is known of the residual radioactivity in the sea below the mixed layer. However it does not contribute to surface radiation fields. No method of prediction is available at this time.*

SURFACE BURSTS

Again for the surface burst, prediction of the residual radioactivity in the sea is extremely difficult for it depends on the unknown factor as to whether one will experience a rising fireball and cloud fallout or crown subsidence as discussed below for the very shallow burst configuration. If one assumes the phenomenon to be similar to a land-surface burst it is suggested that the pool activity will be insignificant, with all of the radioactivity being carried aloft in the fireball or being swept into the fireball in the form of vaporized water. The classical pool would then not exist. However the sea would be contaminated later as the fallout returns to the surface waters. The pool from this latter effect should be of little tactical significance to the fleet.

VERY SHALLOW BURSTS

Both late-emission-column-scavenging and crown collapse will contribute to the development of a well-defined pool of radioactivity at the sea surface. Although no actual measurements of the sea surface fission product concentration have been made for this case,the evaluation of crown collapse contamination after Crossroads-Baker and the interaction of cavity collapse with the column subsidence demand that attention be given to the existence of a pool of radioactivity. The quantity of fission products returned to the sea may be a function of yield and bottom proximity. For low yields, in which crown subsidence is weak, the crown radioactivity will be carried downwind and not deposited immediately in the sea. Bottom proximity may control the distribution of fission products between the underwater bubble cavity and the crown. Such considerations suggest that pool radioactivity intensity will be highest in a bottom-free environment; and where the bottom does interact, the low-yield fractional kiloton shots will scale at a lower level. Of course the initial depth of mixing will be a major determinant of the initial intensity levels, which could be important for very shallow water.

*A mathematical model of this aspect of the problem is being developed at NRDL under ARPA sponsorship.

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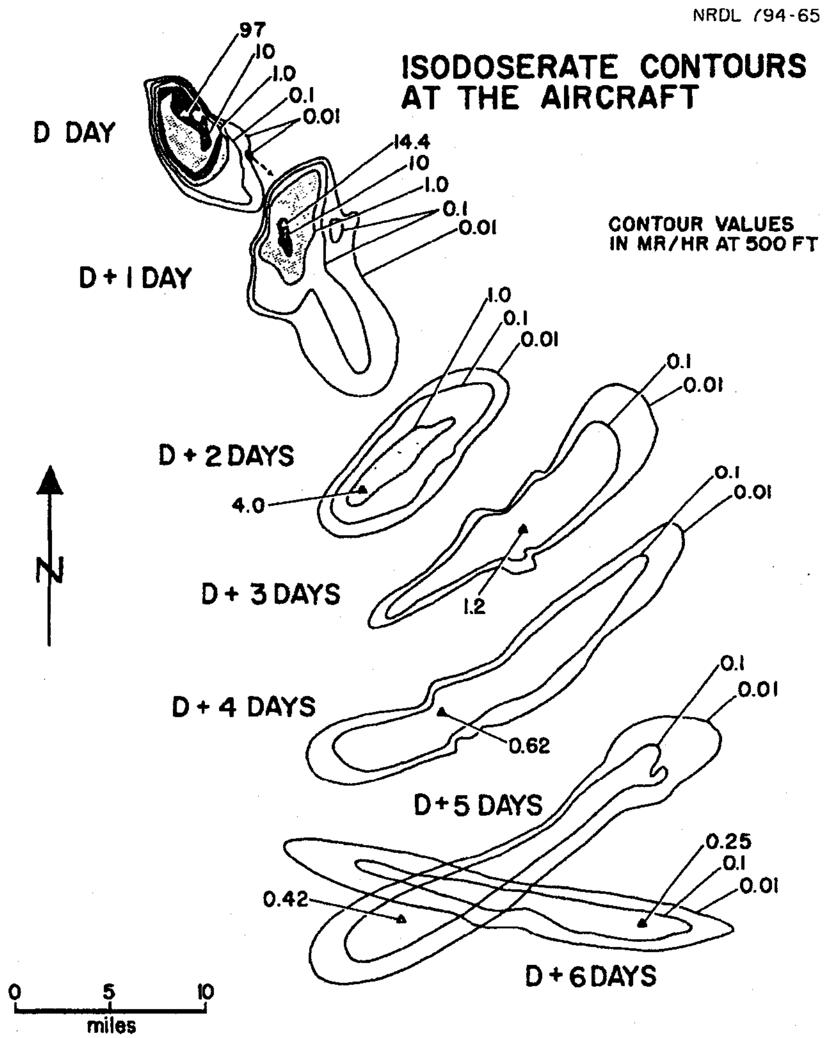

Fig. 11.3:1 Pool Development at Shot Sword Fish

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SHALLOW BURSTS

For this rather well-defined situation it is expected that a large fraction of the fission product debris will return to the surface water of the sea shortly after detonation as a result of the bubble cavity collapse - column collapse interactions. Some 90 percent of the fission products produced will distribute themselves in the mixed layer, with the surface gamma exposure rates being a function of the unknown initial depth of mixing during the first half-hour. However the debris will rapidly mix through the mixed layer in a matter of hours and continue to dilute by horizontal eddy diffusion. It is possible that for shots on the bottom much of the radioactivity will associate with disturbed bottom material and soon settle out.

DEEP BURSTS

For the explosions in the upper part of this scaled depth range that experience little migration, such as Wahoo and Sword Fish, some 67 percent of the total debris (that fraction not associated with the base surge) should be initially in the surface waters. With migration, the problem becomes less clear because of the unknown history of the radioactivity ejected from the bubble at each minimum. The present state of the art permits one to consider this bubble-ejected radioactivity as lost to the surface layers or to consider that the ejected material is carried upward with the hydrodynamic flow along the bubble migration axis to the surface. Should this latter situation exist, it is probable that the radioactive pool would consist initially of water colder than surface water which then would rapidly sink to its own density level. Either phenomenological picture then suggests the pool from deep bursts to be somewhat less radioactive than pools formed by explosions detonated at shallower scaled depths in the range.

VERY DEEP BURSTS

The best evidence for pool radioactivity in this depth range comes from studies of shot Wigwam, for which it has been estimated that some 33 percent of the total fission product production was found in the surface layer several days after the time of detonation. The two-thirds assigned to and below the thermocline layer may however have spent some time at the surface, as discussed above.

EXTREMELY DEEP BURSTS

By definition, bursts in this depth range will suppress or contain all of the radioactivity in the sea beneath the surface mixed layer. The distribution might be envisioned as being spread along the bubble axis with a heavy concentration at the stability barrier at the beginning of the thermocline.

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11.3.5 COMBINED RADIOLOGICAL EFFECTS

Methods and concepts have been described by which the free-field gamma-ray exposure rate and exposure histories may be estimated from the initial radiation,the base surge, and the residual radioactivity in the sea. However, since these three sources overlap each other in time and space the total contribution must consider the integrated radiation fields from each of these sources. Present techniques require that each source contribution be handled as a separate problem and the integrated effect be obtained by addition where appropriate. What is desired is a computational system that will consider all interactions experienced by a ship, submarine or aircraft dynamically involved in an underwater explosion environment.

11.4 SUMMARY OF THE STATE OF THE ART

It is the purpose of this section to state the well understood phenomena and the unknowns that have an influence on predicting the distribution of the radioactive debris and associated nuclear radiation from underwater nuclear explosions and to indicate the direction of present research as well as to suggest future research.

11.4.1 PUBLISHED PREDICTION SYSTEMS AND ESTIMATES OF INPUT PARAMETERS

For the estimation of the extent of the radiological effects from an underwater nuclear explosion, advantage can be taken of existing prediction systems and scaling relationships where available in lieu of any unified model. It will become obvious that the state of the art leaves much to be desired in many areas.

Table 11.4:1 summarizes the useful information available to the reader. It should be emphasized that the tabular data represent, in many instances, subjective estimates requiring further study.

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11.4.2 DIRECTION OF CURRENT RESEARCH

Preparation of a unified prediction system designed to develop the free-field gamma exposure rate contours over all space as a function of time was initiated in FY 1965 by the Defense Atomic Support Agency. This program considers all scaled depths over a wide range of yields using Monte Carlo techniques in the development of the gamma ray transmission aspects of the model. Past nuclear data, high explosive data, and hydrodynamic theory are applied to develop the dynamic source configurations discussed in the preceding sections of this report.

Experimental and theoretical studies are continuing at NRDL and elsewhere as an adjunct to the above project to fill in necessary unknown model parameters.

The final state of the art model will be completed and available for interrogation on high-speed computers at the end of FY 1967.

Related research is continuing at other laboratories with emphasis on bubble phenomena, underwater shock, and air blast.

11.4.3 SUGGESTED FUTURE RESEARCH

If it is assumed desirable to improve the state of the art in the future, further nuclear weapons effects tests or laboratory scaled experiments are considered necessary to update the input variables to the prediction system.

The present state of the art permits evaluation of effects in temperate climates and it is recommended that consideration be given to evaluating the impact of environmental parameters on the phenomenology. Of greatest importance is the problem area of arctic conditions from both the point of view of under-ice explosions and freezing air masses. Further the import of varying stability conditions in both temperate and arctic atmospheres needs study with respect to the fate of the base surge.

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TABLE 11.4:1
Summary of the State of the Art

Scaled Depth Depth	Initial Gamma Radiation Source Geometry	Mass Distribution	Estimated Fission Product Fraction	Chronology	Rem
Surface	1. For high yields (> 50 KT) like land surface burst 2. For yields less than 10 KT, unknown	1. Fireball 2. Unknown	1. 100 % 2. Unknown	1. Rising fireball 2. Unknown	1. As an interim m land fallout pr (ref. Cassidy) 2. May resemble ve depth range
Very Shallow	Aerosol crown capping column	Unknown mixture of air and water. Bulk density variable with yield; $\sim 4\ \rho_{air}$ (?)	10 % for shots in deep water 50 % for shots on or near bottom	Early crown formation. Crown subsides for yields > 10 KT little subsidence for fractional KT	Several outdated p all incomplete.
Shallow	Hollow column	Column walls consist of unknown mixture of air and water $\rho \sim 4\ \rho_{air}$ (?)	Variable in time; small	F.P. rise above surface with bubble, then reverse completely and return to underwater bubble cavity	No available predi Contribution to to expected to be neg
Deep	Hemispherical plume May be columnar from deeper shots	Uniform (?) Unknown mixture of air and water $\rho \sim 4\ \rho_{air}$ (?)	100 % in upper part of scaling range Unknown when bubble experiences several oscillations	Gradual collapse of plume which initiates base surge	No available predi Gamma fields produ considered negligi
Very Deep	Hemispherical plumes	See deep category	Unknown	See deep category	See deep category
Extremely Deep	No atmospheric interaction	-	-	-	-

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TABLE 11.4:1
Summary of the State of the Art

pth	Initial Gamma Radiation					Base Surge Radiation			
	Source Geometry	Mass Distribution	Estimated Fission Product Fraction	Chronology	Remarks	Source Geometry	Mass Distribution	Estimated Fission Product Fraction	Chronology
	1. For high yields (> 50 KT) like land surface burst 2. For yields less than 10 KT, unknown	1. Fireball 2. Unknown	1. 100 % 2. Unknown	1. Rising fireball 2. Unknown	1. As an interim measure use surface land fallout prediction system (ref. Cassidy) 2. May resemble very shallow scaled depth range	1. Not applicable 2. Unknown	1. Not applicable 2. Unknown	1. Not applicable 2. Unknown	1. Not applicable 2. Unknown
	Aerosol crown capping column	Unknown mixture of air and water. Bulk density variable with yield; $\sim 4\ \rho_{air}$ (?)	10 % for shots in deep water 50 % for shots on or near bottom	Early crown formation. Crown subsides for yields > 10 KT little subsidence for fractional KT	Several outdated prediction schemes; all incomplete.	Annular aerosol ring	Low density water air mixture $\rho < 2\ \rho_{air}$ (?)	10 % if shot fired in deep water 5 % if shot fired on or near bottom Fractionated mixture	Rapid radial expansion. Drifts with wind. Influenced by atmospheric variables.
	Hollow column	Column walls consist of unknown mixture of air and water $\rho \sim 4\ \rho_{air}$ (?)	Variable in time; small	F.P. rise above surface with bubble, then reverse completely and return to underwater bubble cavity	No available prediction system. Contribution to total gamma field expected to be negligible	Annular aerosol ring	See very shallow category	10 % Fractionated mixture	See very shallow category
	Hemispherical plume May be columnar from deeper shots	Uniform (?) Unknown mixture of air and water $\rho \sim 4\ \rho_{air}$ (?)	100 % in upper part of scaling range Unknown when bubble experiences several oscillations	Gradual collapse of plume which initiates base surge	No available prediction system. Gamma fields produced generally considered negligible.	Annular aerosol ring FP may extend throughout center annulus	See very shallow category	33 % in upper part of scaling range Unknown when bubble experiences several oscillations	See very shallow category
	Hemispherical plumes	See deep category	Unknown	See deep category	See deep category	See deep category	See very shallow category	10 %	See very shallow category
	No atmospheric interaction	-	-	-	-	-	-	-	-

ks	Base Surge Radiation: Source Geometry	Base Surge Radiation: Mass Distribution	Base Surge Radiation: Estimated Fission Product Fraction	Base Surge Radiation: Chronology	Base Surge Radiation: Remarks	Oceanic Pool Radiation: Source Geometry	Oceanic Pool Radiation: Mass Distribution	Oceanic Pool Radiation: Estimated Fission Product Fraction	Ch
sure use surface iction system shallow scaled	1. Not applicable 2. Unknown	1. Not applicable 2. Unknown	1. Not applicable 2. Unknown	1. Not applicable 2. Unknown	- -	1. Unknown 2. Unknown	1. Unknown 2. Unknown	1. Unknown 2. Unknown	1. 2.
diction schemes;	Annular aerosol ring	Low density water air mixture $\rho < 2\ \rho_{air}$ (?)	10 % if shot fired in deep water 5 % if shot fired on or near bottom Fractionated mixture	Rapid radial expansion. Drifts with wind. Influenced by atmospheric variables.	See Huebsch (1963a). Use with caution for prediction purposes.	Radially expanding surface water mass	Unknown at early times Eventually mixes to top of thermocline	60-70 % if shot fired in deep water. Variable with yield and bottom proximity for shallow water	In al sh zo gr di
ion system. l gamma field gible	Annular aerosol ring	See very shallow category	10 % Fractionated mixture	See very shallow category	See Huebsch for prediction purposes	Radially expanding surface water mass	See very shallow category.	90 %	Se ca
ion system. d generally e.	Annular aerosol ring FP may extend throughout center annulus	See very shallow category	33 % in upper part of scaling range Unknown when bubble experiences several oscillations	See very shallow category	See Huebsch, use with caution for prediction purposes when bubble experiences several oscillations	Radially expanding surface water mass Possible sub-surface pools.	Unknown at early times surface pool eventually mixes to top of thermocline unknown for sub-surface pools	67 % in upper part of scaling range - surface pool Unknown contribution to surface and sub-surface pools if bubble experiences several oscillations	Se ca pa ra Un su
	See deep category	See very shallow category	10 %	See very shallow category	See Huebsch, use with caution for prediction purposes	See deep category	See deep category	33 % in surface pool 67 % in sub-surface pools	Se ca
	-	-	-	-	-	Sub-surface pools below the mixed layer	Unknown	100 % in pools below the mixed layer	Un

Remarks	Oceanic Pool Radiation					Discussion
	Source Geometry	Mass Distribution	Estimated Fission Product Fraction	Chronology	Remarks	
-	1. Unknown	1. Unknown	1. Unknown	1. Unknown	-	1. For high yields - major contamination by fallout.
-	2. Unknown	2. Unknown	2. Unknown	2. Unknown	-	2. Phenomenon unknown - may resemble either land surface burst or very shallow underwater burst or both.
See Huebsch (1963a). Use with caution for prediction purposes.	Radially expanding surface water mass	Unknown at early times Eventually mixes to top of thermocline	60-70 % if shot fired in deep water. Variable with yield and bottom proximity for shallow water	Initially dynamically driven by shot - further horizontal and vertical growth by eddy diffusion.	No adequate prediction available for first half hour. See Ksanda (1963) for later times	Subsiding crown and bottom influence make predictions in this range very difficult. Ref. shot: Crossroads Baker.
See Huebsch for prediction purposes	Radially expanding surface water mass	See very shallow category.	90 %	See very shallow category	See very shallow category	Best understood range. Ref. shot: Hardtack Umbrella
See Huebsch, use with caution for prediction purposes when bubble experiences several oscillations	Radially expanding surface water mass Possible sub-surface pools.	Unknown at early times surface pool eventually mixes to top of thermocline unknown for sub-surface pools	67 % in upper part of scaling range - surface pool Unknown contribution to surface and sub-surface pools if bubble experiences several oscillations	See very shallow category for upper part of scaling range Unknown for sub-surface pools	See very shallow category for upper part of scaling range. No prediction system available for sub-surface pools.	This depth range is too broad covering shots that have little migration to those having multiple migration. Ref. shots: Hardtack Wahoo and Sword Fish
See Huebsch, use with caution for prediction purposes	See deep category	See deep category	33 % in surface pool 67 % in sub-surface pools	See deep category	See deep category	Underwater hydrodynamics poorly understood. Ref. shot: Wigwam
-	Sub-surface pools below the mixed layer	Unknown	100 % in pools below the mixed layer	Unknown	No prediction system available	Very little known on possibility of achieving these conditions

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BIBLIOGRAPHY

Buntzen, R. R., "The Underwater Distribution of Explosion Products From a Submerged Exploding Wire (U)," USNRDL-TR-778, 31 July 1964, (Unclassified).

Caputi, R., "Theoretical Model for Molecular and Particulate Interaction with Water Aerosol (U)," USNRDL-TR-463, 19 September 1960, (Unclassified).

Cassidy, S. H., "The Fortran Statement of the Computer Program for the USNRDL Dynamic Fallout (D) Model (U)," USNRDL-TR-637, 22 March 1965, (Unclassified).

Cole, R. H., "Underwater Explosions," Princeton University Press, 1948.

Egeberg, L. E., et al, "Radiological Effects from an Underwater Nuclear Explosion (U)," Project 2.1, Operation Dominic, U. S. Naval Radiological Defense Laboratory, POR-2004 (Published by DASA), 14 June 1963, (Secret-RD).

Evans, III, E. C., T. H. Shirasawa, "Characteristics of the Radioactive Cloud from Underwater Bursts (U)," Operation Hardtack, Project 2.3, U. S. Naval Radiological Defense Laboratory, (Published by DASA), WT-1621, 15 January 1962 (Confidential-FRD).

Folsom, T. R., "Mechanism and Extent of the Dispersion of Fission Products by Oceanographic Processes and Locating and Measuring Surface and Underwater Radioactive Contamination (U)," Project 2.6-2, Operation Wigwam, Scripps Institution of Oceanography, WT-1015 (Published by DASA), July 1956, (Confidential-FRD).

Gurney, W. J., P. A. Killeen, "Hydra Program - Hydra IIA Series; Distribution of Explosion Products in the Above Surface Phenomena of Very Shallow and Shallow Underwater Explosions (U)," USNRDL-TR-785, 6 July 1964, (Confidential).

Hammond, R.R., "Hydra Program-Hydra IIB Series - An Investigation of Water Flow Adjacent to Shallow Underwater Explosion Bubbles with Fluorescent Dyes and Photographic Techniques (U)," USNRDL-TR-968, 3 August 1965, (Unclassified).

[redacted]

Hendricks, J. W., D. L. Smith, "Above-and Below-Surface Effects of One-Pound Underwater Explosions, Hydra I (U)," USNRDL-TR-480, 18 October 1960, (Unclassified).

Huebsch, I. O., "Preliminary Analysis of Base-Surge Dose Contours for Nuclear Bursts of Above 100 KT at Selected Depths (U)," USNRDL-LR-6, March 1963, (Secret).

Huebsch, I. O., "A Model for Computing Base-Surge Dose-Rate Histories for Underwater Nuclear Bursts (U)," USNRDL-TR-653, 27 May 1963, (Confidential).

Isaacs, J. E., "Mechanism and Extent of the Early Dispersion of Radioactive Products in Water (U)," Project 2.6-1, Operation Wigwam, Scripps Institution of Oceanography, WT-1014 (Published by DASA), 28 March 1962, (Unclassified).

Kahn, H., "Applications of Monte Carlo (U)," Rand Corporation, AECU-3259, (Published by AEC), 27 April 1956, (Unclassified).

Kaulum, K. W., "Hydra Program - Hydra IIB Series; Investigation by Water Sampling of the Internal Structure of Columns Resulting From Small Underwater Explosions (U)," USNRDL-TR-706, September 1963, (Unclassified).

Kaulum, K. W., "Hydra Program - Hydra IIB Series; Transfer and Distribution of Traced Explosion Products to the Columns of Shallow Underwater Explosions (U)," USNRDL-TR-954, 30 Sept. 1965 (Confidential).

Keil, A. A., "Introduction to Underwater Explosion Research (U)," Underwater Explosions Research Division, Norfolk Navy Shipyard, UERD 19-56, December 1956,(Confidential).

Kennard, E. H., "Underwater Explosions - A Summary of Results (U)," David Taylor Model Basin, TMB-R-182, December 1943, (Unclassified).

Kot, C. A., "Hydra Program: Theoretical Study of Bubble Behavior in Underwater Explosions (U)," USNRDL-TR-747, 15 April 1964, (Unclassified).

Ksanda, C. F., et al, Chapter 7 of "Weapons Effects Predictions for Operation Willow Surface/Subsurface Events (U),"USNRDL-TR-346, September 1959, (Secret).

Ksanda, C. F., E. Laumets, "Computation of Early-Time Fission Product Dose-Rate Spectra and Gamma-Ray Air Attenuation (U)," USNRDL-TR-361, 14 September 1959, (Unclassified).

Ksanda, C. F., "Analysis and Prediction of the Properties of Diffusing Radioactive Pools from Nuclear Explosions in the Ocean (U)," USNRDL-TR-725, 19 December 1963, (Confidential).

McEnhill, J. J., "Photographic Studies of Small Scale Shallow Underwater Explosions (U)," Atomic Weapons Research Establishment, AWRE 0-77/54, January 1955, (Secret).

Perkins, W. W., "Hydra Program - Hydra IIA Series; The Above-Surface Phenomena Created by 10,000-Pound Underwater Detonations (U)," USNRDL-TR-708, 28 October 1963, (Confidential).

Pritchett, J.W., "Explosion Product Redistribution Mechanisms for Scaled Migrating Underwater Explosion Bubbles (U)," USNRDL-TR-1044, 23 May 1966, (Unclassified).

Rainey, S. C., R. W. Shnider, "Preliminary Weapons Effects Predictions for AEC Diagnostic Weapons Test Series (U)," USNRDL-TR-552, 13 March 1962, (Secret).

Russell, G. A., R. Zirkind, "Nuclear Radiation From Underwater Detonation (U)," Bureau of Aeronautics, DR-1825, November 1957, (Secret).

Schuert, E. A., L. B. Werner, "Nature of the Radioactive Debris and Nuclear Radiation Associated with an Underwater Nuclear Explosion (U)," USNRDL-479; DASA-1240, 27 January 1964, (Secret-Restricted Data).

Shirasawa, T. H., "Early Dimensions and Radiation Intensities of the Radioactive Pool Resulting from Shot Sword Fish (U)," USNRDL-TR-770, 15 July 1964, (Secret-FRD).

Shnider, R. W., "The Interaction of Surface Ships with the Thermal and Radiological Environment (U)," USNRDL-475, DASA-1240-II(4), 20 January 1964, (Secret).

Snay, H. G., et al, "Predictions of Underwater Explosion Phenomena (U)," U. S. Naval Ordnance Laboratory, WT-1004 (Published by DASA), May 1956, (Secret-RD).

Snay, H. G., "The Hydrodynamic Background of the Radiological Effects of Underwater Nuclear Explosions (U)," In Proceedings of Tripartite Symposium on Technical Status of Radiological Defense in the Fleets, Volume 2, USNRDL-R&L-103, 16 May 1960, (Confidential).

Snay, H.G. "Hydrodynamics Concepts - Selected Topics for Underwater Nuclear Explosions (U)" DASA-1240-1(2), NOL TR 65-52, 15 Sept 1966 (Unclassified).

[redacted]

Soole, B. W., "Surface Phenomena at Operation Hurricane (U)," in Proceedings of Tripartite Symposium on Technical Status of Radiological Defense in the Fleets, Volume 3, USNRDL-R&L-103, 16 May 1960, (Secret).

Spencer, L. V., U. Fano, Phys. Rev., 81:464L, 1951.

Spencer, L. V., U. Fano, J. Res. Nat. Bur. Stds., 46:446, 1951.

Spin Drift Effects Handbook, Edition 2, United Research Services, URS-192-6, 1 Sept. 1964, (Secret-RD).

Strope, W. E., "Investigation of Gamma Radiation Hazards Incident to an Underwater Atomic Explosion (U)", USNRDL-TR-687, 5 November 1963, (Confidential).

Swift, E., G. A. Young, "Surface Phenomena From Underwater Bursts (U)," U. S. Naval Ordnance Laboratory, WT-1608 (Published by DASA), March 1962, (Confidential, FRD).

Ulberg, J. C., "A Mathematical Model for Predicting Rain-Out by Water Drop Coalescence in Base Surge Aerosols (U)", USNRDL-TR-696, 23 September 1963, (Confidential).

Wesley, E. J., et al, "Aerial Survey of the Surface Radioactivity Remaining After an Underwater Nuclear Detonation (U)," Operation Dominic, USNRDL-TR-626, 4 March 1963, (Secret).

Young, F. H., R. R. Hammond, "A Non-Spherical Model Describing the Motion of a Shallow Underwater Explosion Bubble (U)," USNRDL-TR-771, 23 June 1964, (Unclassified).

Young, G. A., "A Method for Estimating the Initial Gamma Radiation Dosage From an Underwater Burst of a Nuclear Weapon (U)," U. S. Naval Ordnance Laboratory, NAVORD-4215, 1 May 1956, (Confidential).

Young, G. A., "Surface Phenomena of Underwater Nuclear Explosions (U)," U. S. Naval Ordnance Laboratory, NOL-TR-63-111, 1 July 1963, (Secret RD).

Young, G. A., "Micrometeorological Phenomena of Underwater Nuclear Explosions (U)," U. S. Naval Ordnance Laboratory, NOLTR-64-187, 14 January 1965, (Unclassified).

Young, G.A., "The Physics of the Base Surge (U)," U. S. Naval Ordnance Laboratory, NOLTR-64-103, 17 June 1965, (Unclassified).

Zirkind, R., et al, "Estimated Surface Nuclear Dose From Underwater Nuclear Detonations (U)," Bureau of Aeronautics, DR-1825A, January 1958, (Secret).

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13. ABSTRACT

A technical review of the literature on the distribution of the radioactive debris and the associated nuclear radiation from underwater nuclear explosions is presented. This review, or material based on it, is to be included as Chapter 11 in the planned DASA book Underwater Nuclear Explosions, Part 1 - Phenomena. (U)

The history of the fission products is followed from the time of detonation. The free-field gamma radiation phenomena are discussed for surface, very shallow, shallow, deep, very deep, and extremely deep scaled depth ranges by evaluation of three major sources: the early above-surface phenomena, the base surge, and the residual radioactivity in the ocean. (U)

The state of the art is summarized, and the direction of current research and suggested future research are discussed. (U)

It is concluded that no adequate comprehensive radiological prediction system exists in the literature for underwater nuclear explosions. (U)

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